AGRICULTURE

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THE SCIENCE OF AGRICULTURE

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PREFACE.

THE following pages are mainly a reproduction of lectures delivered at King's College, London, in which an attempt was made to explain, with as little use of technical language as possible, the scientific principles which regulate the modern practice of agriculture.

My chief inducement to publish them has been the long-felt want frequently expressed to me by farmers of a work from which they could learn some of the bearings of modern science on their art. This want I have endeavoured to satisfy, and the analyses, which necessarily form the basis of much of the subject matter, were, if not otherwise stated, made by myself.

To make the work useful to the agricultural student it was necessary to enter briefly into a description of practical operations, and I have striven, by personal conversation with leading agriculturists and by careful study of our agricultural literature, to avoid any erroneous statements on the aspects of farming with which I am least familiar. I am specially indebted to Mr. W J. MALDEN, of the Royal Agricultural Society's Experimental Farm at Woburn, for much valuable information with regard to farm practice, and for revising the proof sheets of the chapter on 'The Treatment of Farm Crops.'

I trust these pages will be a safe guide to the Science of Agriculture, that they will throw a new light upon old operations, give fresh interest to the routine of the farm, and elucidate the only true means by which to contend against adverse circumstances and increasing foreign competition.

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THE

SCIENCE OF AGRICULTURE.

CHAPTER I.

INTRODUCTORY.

Agriculture is an art. How, then, can agriculture be learned from a text-book? This question, naturally occurring to the mind of one who devotes any thought to the subject, must force itself strongly on the minds of those who, having followed agriculture as a means of livelihood, have seldom, if ever, studied any book upon the subject. That such men exist there can be no doubt; therefore, unless it can be shown that such men would have proved better able to cope with their difficulties, provided they had obtained the book-learning which they professedly have not, or unless there are circumstances and conditions surrounding the present pursuit of agriculture different to those which formerly existed, there can be no use for this book. Arguing from analogy in the first place, it may be stated that with the development of every art, practice alone has preceded all principles. With the gradual development of the latter out of the former, there has arisen the more thorough and the more practical method of first studying the principles, and then putting them into practice. This may be termed the scientific method of study. If we take music and painting among the fine arts, and surgery and medicine of the applied arts, we find that this has been the method alike of their gradual development and study. The question therefore arises, has agriculture reached that position in which its study, forsaking the old system, should start now upon the newer and more scientific method of principles first, and practice subsequently?

If we go back in the history of agriculture some fifty years, we come to a time when chemistry and physiology were comparatively in their childhood, and had neither come to the help of practical agriculture, nor thrown any light upon the multitudes of scientific problems which it presented. During that fifty years, and especially during the last half of them, those sciences have made prodigious strides. Slowly, but none the less surely, their influence has been felt, and indirectly in the majority of cases, but directly in very many, they have materially affected practical agriculture. They have helped the farmer to overcome difficulties formerly insurmountable, enabling previously barren soils to prove fertile by the use of artificial manures, and live stock to reach maturity, in incredibly short periods, by the use of artificial feeding materials. Even when they have not interfered with agricultural practice, they have explained the fundamental principles which underlay it. Hence we see that the farmers of the past were compelled to be content with practice alone, because the scientific learning of the present day did not exist.

Further, with the growth of this learning there have arisen circumstances which already affect the pursuit of agriculture, and tend daily to bring about conditions entirely different to those which formerly existed. Unfortunately the men who should be first to recognise the signs of the times are, alas! only too backward. Agriculture alone, of all the arts cultivated in England, is still supposed to be best learnt by practice, without either the previous or simultaneous study of the principles upon which it is founded. A generally accepted notion is abroad that there is little for the farmer to learn away from the field, either in lecture room or text-book. Before entering into any detailed description of the science which underlies all farming operations, it is necessary therefore for the reader to thoroughly realise that this science actually exists. At the same time he will obtain a general view of the ground which he is subsequently to thoroughly study. Then, seeing the advantages which may reasonably be expected to follow that study, he will be prepared to pursue it with diligence.

We call the simple laws of addition and subtraction laws of arithmetic. They are none the less laws of nature. The whole progress of nature, the transformation of substances into each other, is shown by science to be simply a process of addition and subtraction. Nothing is lost, nothing is gained; what is has been, and will be, however varied the forms it may assume; and this is true not merely of matter, but also of force. The plant grows during the spring and summer, and a vast weight of substance is added to it. That substance has been subtracted from somewhere.

The animal in the stall is daily gaining in weight, it is adding flesh; that flesh has been abstracted from somewhere. From whence? and by what forces? are the questions we ask in each case.

Now, practice can give us no real answer to these questions. We may say that the plant has lived upon the soil, and the animal upon its food; but the plant has not required all the soil, nor the animal all its food, and therefore practice can only give a very partial answer to the questions. We must look to science for the complete and thorough answer. Then, having learnt the nature of the changes which have taken place, and the laws which governed those changes, we may reasonably hope to utilise the materials and forces of nature. This is the true business of the farmer. The products which he obtains are the reward due to him for the labour he has expended. According, therefore, to his ability in utilising the materials and forces of nature, so will be his success as a farmer. How can one who is ignorant of the materials with which he has to deal, and the inviolable forces which govern them, hope to be successful?

The business of the farmer may be classified into four divisions, corresponding to some extent with the four seasons, provided the year commence with the autumn quarter. They are:—

1st. The improvement of the soil.
2nd. The cultivation of the soil.
3rd. The production of crops.
4th. The rearing of live stock.

These are the four great divisions of agricultural work, and it will be well to briefly notice some of the many points in each, where science has been the handmaid of practice.

In the improvement of the plough and the introduction of steam into the working of the farm, mechanical science has done so much for agriculture that it is scarcely possible to estimate it. By steam ploughing alone land may be cultivated which by horse-power could scarcely have been cultivated at all. Even in the hand plough, so great has been the improvement in strengthening the instrument, and yet lightening its weight, that a man and horse can perform in a few days what some years ago would have required much longer time, even if it could have been performed at all by the same horse-power. This improvement may be due to the improved material from which the plough is manufactured, but it is also very greatly due to a more accurate knowledge of what were the mechanical principles utilised in the plough in cutting up the earth and turning it over. The principles of mechanics are called into play in the construction and use of every machine, and the plough is only one of very many farm implements which an improved knowledge of mechanics has modified to the advantage of the farmer.

Chemical science has of all sciences been the most prolific of help to agriculture.

An experienced farmer, passing from field to field, may by mere sight and touch gain some idea of the nature of the soil, and of the cultivation it will require; but this knowledge is uncertain, and mistakes may and frequently do occur. If chemistry, however, be consulted, its answer is certain. The analysis of a soil will reveal not merely its superficial characteristics, but its hidden properties. Now, it is not requisite that the farmer should be able to make these analyses, any more than he should make his own plough. But he should have sufficient knowledge of the science of chemistry as applied to agriculture to understand and benefit by the analysis when he has it, just as he should have a sufficient knowledge of mechanics to know when buying a plough whether it is constructed on good mechanical principles or not. But the analysis of the surface soil will not tell him everything, and to it should be added some knowledge of geology; by this means it will be easy to understand somewhat more of the nature of a soil than even chemical analysis may show, and it greatly tends to answer two questions—what the physical character of the soil will be under different conditions of climate, and also what chances there are of the subsoil being brought to the surface with advantage. Experience has shown that while in some cases the under-soil may be brought to the surface, and so improve the land; in others it will diminish the fertility of the soil, and may even prove absolutely injurious.

There is a remarkable instance of the value of scientific knowledge to the farmer, especially of geology and chemistry, in the immense improvements which many years ago took place at Holkham, in Norfolk, and which have been admirably described as follows: 'It is to the first Earl of Leicester that the surpassing beauty and wealth of the Holkham estates are due. He had the reputation of being the first farmer in England. On his estate the surface soil was sand, but below there was marl. He ploughed deep, spread the marl, and changed the character and the value of the soil. We find in the "Norfolk Tour" that half a century before Norfolk might be termed a rabbit and rye country. In its northern part wheat was almost unknown. In the whole tract lying between Holkham and Lynn not an ear was to be seen, and it was scarcely believed that an ear could be made to grow Now the most abundant crops of wheat and barley cover the entire district.' Here we see how a knowledge of geology as applied to agriculture was admirably and profitably employed. The Earl probably knew that the marl would not only contain food for plants which was absent in the natural sandy top-soil; but he also knew that it would confer upon this sandy soil many qualities which would greatly improve it as a bed for sowing seed in, and without which properties it could not possibly grow good crops. A more striking example of the advantages which a practical agriculturist has gained by scientific knowledge is seldom met with. How useful, then, it will be to know somewhat of the nature of the rocks from which soils have been made, the composition of these soils, and the peculiar properties they possess, whether they are good or bad!

The peculiarities of soils depend, however, not only on the rocks from which they have been formed, but upon the treatment to which the farmer subjects them by means of ploughing and other farm operations.

What further aid has chemistry given the farmer? When man enters a tract of country hitherto uncultivated, and the forest is cleared to obtain land for farming, then the ground is covered with a rich soil. This is called virgin soil. If upon it any crop be grown, it will as a rule be good, and many good crops may succeed it. Such soil would be called fertile. In course of time the crops begin to diminish, and if the cropping continues long enough, a time comes when the soil will no longer yield a profitable crop, even should it yield a crop at all. The natural fertility of the soil will have been exhausted. This is the condition of very many soils in England, which are not capable of growing good and profitable crops from the fertility they contain naturally.

The cause of this inability to grow crops was for long unknown, after experience had taught men the fact. Even at the present day the phenomenon is not entirely understood, though its principal cause has been discovered. By the aid of chemistry it has been proved that the plant takes from the soil certain substances in order that it may grow. These substances have consequently been termed plant food. By the continuous growth of crops the soil becomes exhausted of this plant food. Thus was discovered the cause of the gradual decrease in the fertility of soils. The remedy was evident. Put these substances back into the soil. It was easy to say, Put these substances back into the soil; the difficulty was where to find them. The teachings of chemistry solved this problem likewise. Half a century ago one single substance, and one only, was used for the purpose—namely, bone. Now there are hundreds of substances so employed, and they are termed artificial manures.

At the present day farming could not be carried on in England and other countries to the extent which it is if it were not for the use of these artificial manures. Now, these manures are infinitely varied, and the practical man would be bewildered as to which to use if he were ignorant of their composition. Chemistry alone can teach him this, and probably in no aspect of farming has science been of greater benefit and importance than in teaching farmers the composition and right use of artificial manures. Not only does chemistry teach the right use of manures, but, recognising how great is the expenditure which a farmer makes yearly on manures, it also enables him, by means of analyses, to see that he obtains his money's worth. Unfortunately, many farmers are ignorant of the value of the analysis of a manure, and buy anything so long as it has a powerful smell and is cheap. Hence they are greatly imposed upon, and, finding but little benefit arise from the use of their artificial manure, they jump to the conclusion that artificial manuring is altogether a mistake. Thus ignorance begets error.

Before attempting to see how science has benefited the farmer with regard to the cultivation of his crops, it will be well to remember that practice preceded science. Many of the operations which were in vogue before science came to elucidate their accuracy and explain the reasons of their success, were probably discovered centuries ago, and have remained in existence owing to that law of nature known as 'the survival of the fittest.' Hence it is that the custom prevailing in one county differs from that in an adjoining county, because, for some reason, or reasons, the one practice was fittest in the one place, the other in the second place.

Practical men evidently discovered in very early times that it was impossible to grow corn year after year upon the same land. Hence we find that centuries ago the custom was to grow corn one year, and leave the soil bare the next, without any crop. With an increase in the number of substances grown, these became taken in certain order, or in a certain rotation. There arose in Norfolk a system of such rotations of crops, which, proving of considerable advantage, soon gained ground, until at last it left all other systems in the background. This rotation consisted of four different crops, one for each year, and became known as the Norfolk, or four-course, system of rotations. Many other systems of rotation are also adopted. Now, there is considerable scientific evidence to account for the advantage of these rotations; and thus it is possible to determine which would be the best rotation to adopt under given conditions. So beneficial was the effect produced by growing crops in a definite order, as compared with the practice which had preceded it, that systems of rotations became stereotyped. Recently, men have come to consider another side of the question. Is the practice invariably correct? The answer lately given to this question by the best practical agriculturists is decidedly in the negative. Agriculture has recently passed through trying times, and this system of rotations has been severely tested; it is thought by some to have failed, because those who have not adhered to it, but have been guided by other principles, have passed through the bad times better than those who followed it blindly.

Those who broke through the old system and adopted a new one, must have had good reasons for so doing, and presumably a safe guide to direct them in their new course. What was this guide? Scientific principles. They thoroughly understood the reasons for the value of rotations, and hence were able to break through the system which the weather or other circumstances had rendered inadequate.

Thus practice came first, and improved upon old methods by introducing the system of the rotation of crops. Then came science, and, having carefully examined everything connected with this system, it was enabled to explain why the results obtained were so good, and the system beneficial. Now, practice, acting upon this store of scientific knowledge, is able, when necessary, to break through the old custom, and start a new one better adapted to the conditions of the times. What can be a more striking proof than this of the immense value which the knowledge of science, as applied to agriculture, will have for the farmer of the future?

Having explained the rationale of the systems of rotation, and shown how they might be modified, scientific men set themselves this problem: Is it possible to break through these rotations altogether, and grow crops of the same substance year after year on the same ground? Experiments carried on in experimental fields showed that it was possible, under certain conditions. Then came the practical question: Can it be done profitably? Farming being a business, and like in all businesses profit being the chief consideration, science, unless it can help farming to be more profitable, is of little use to the practical man. But science is true knowledge—and all true knowledge, rightly applied, will prove profitable. Consequently we find it now demonstrated by Mr. John Prout, of Sawbridgeworth, that crops can be grown continuously and also profitably. While in this one instance, perchance in several others, the system of continuous growth has succeeded, in many instances it has completely failed ; and whilst every success has been due to a happy combination of practical skill with scientific knowledge, so there is reason to believe that every failure has been due to a want of accurate scientific knowledge rather than to any deficiency in practical skill. This is unfortunately not the only instance of an unequal balance of practical skill with scientific principles.

Upon the culture of individual crops the science of botany has thrown considerable light. If chemistry has taught us the composition of the plant, botany has taught us its individual peculiarities, and hence men have been enabled to cultivate those plants which chemistry has shown to be the most advantageous for their use.

In the selection of seed, in the propagation of varieties, and in procuring the fittest plants or varieties of plants for varying conditions of soil and climate, botany has proved of considerable advantage to the farmer. It has investigated the nature of those vegetable parasites to which plants are liable, has shown what many of our diseases of crops are due to, and so helped the chemist to advise the farmer how to protect his crops against these diseases, or, on the other hand, how to prevent the spread of the disease when it has once appeared.

The study of the physiology of plant life has already been fruitful of much advantage to the farmer, and bids fair to be of still greater advantage in the future. Physiological botany taught that, in the early stages of the growth of the plant, certain substances were formed in greater quantity than in the latter stages of growth. It seemed probable, therefore, that at this period of the growth of the plant the constituents necessary to form these substances would be of most value. Scientific men, therefore, tried the application of manures, containing these substances, just at that time when the young plant needed them. The result was startling; the crops attained a perfection seldom before reached. Now the scientific experiment has become a universal practice. A second, and quite unexpected, result followed. It was found that in those years when blight attacked the young plants, those plants which had been manured were less liable to it, and better able to withstand and to overcome it, than those unmanured; so that plants in whose cultivation the teachings of science had been utilised were, if not entirely, yet to a considerable extent, unhurt.

A crop, when raised, must, unless it be one which is eaten on the field, be reaped and stored away. It might not seem of much importance when these operations took place, provided it suited the farmer and the weather. This, however, is not so. Botany and chemistry show that a plant gradually matures, then produces seed, then deteriorates, or rather becomes slowly less nutritious, less valuable for feeding purposes, and hence less useful to the farmer. Consequently some of the simplest operations of the farm, such as the time of gathering in a crop, should really depend upon definite laws, and not mere chance circumstances. This is one only of the many important steps which science has enabled practical farmers to take to supply food not merely for the rearing of live stock, but indirectly for the consumption of man.

The growing tendency of the age is to increase in England the number of stock-breeding farms, because the facility with which we are able to import corn and seeds from other countries has considerably lowered the price of these substances, whilst the price of meat has, during the same period, correspondingly risen. Hence many farmers are yearly cultivating less arable ground, and putting more down to permanent pasture. Already, statistics show that more than half the cultivated ground of England is laid down in permanent pasture for the rearing of stock. The benefits of science have been felt in the application of chemistry and botany to the improvement of this permanent pasture. If a field be closely examined, the herbage will be found to consist of a great number of grasses, possessing but slight differences; and upon passing into another field, here again new kinds of grasses will appear, while those found in the first field are absent. Now, the practical man would simply say the one field was better or worse than the other, because experience would have taught him that it would yield more or less food—in other words, feed more or less cattle. Science was not content with this dictum. Acting upon the principle which underlies all true science, that there is a reason for everything, it sought to find that reason out. To a great extent it has succeeded, though there is still much to learn. The chemist, however, has taken these various grasses, analysed them, and by this means found out which are the most nutritive. Further, by the aid of botany, it has been shown how these rich grasses may be preserved, and the poor grasses eliminated. Hence a given area of land will now grow not only more grass than heretofore, but that grass of a select kind; and the farmer is consequently able to keep upon that area of land a far larger number of cattle than formerly.

The period of the year during which cattle can be out at grass is limited, and at certain times it is necessary they should be fed indoors, or what is termed stall-fed. Hay and grain were formerly used almost entirely for feeding them in the stalls, but of late years a great variety of substances have been shown by chemical analysis, and proved by experience, to be equally capable of being employed as food. Before the use of these artificial foods, animals took far longer to come to perfection than they now do, and so it may truly be said that, owing to science, the time which an animal must be on a farmer's hands before it is ready for the market has been greatly shortened. Further, the animal as sent to the market now differs considerably, in both size and composition, from the animal as sent years ago.

A greater knowledge of the physiology of animal life has furthered this end. All the processes which take place within the animal body, what portion of the food the animal will retain, what portion it will not assimilate, are now known. Combining this knowledge with the knowledge of the composition of foods, it is easy so to arrange the diet of an animal as to fit it for whatever purpose it is required to fulfil.

Everyone knows how varied are the sheep and cattle which are to be seen in different parts of England. Why is this? The answer most people would be likely to give is, that it is natural, or has always been so. This answer, however, is very wide of the mark. It is probably true that many of these varieties have existed for ages. But others are of comparatively recent origin, and these are the direct result of domestication. Of the various breeds of cattle, for instance, some are best suited to perform the part of milch cows, others to fatten for market. Acting upon this knowledge, and upon the knowledge of the laws of heredity, man has taken into his hand the artificial selection of cattle. Probably natural selection had to a great extent brought about the various brceds which exist in England; now science has taken the matter in hand, and accident is replaced by law. A definite object is in view in the breeding of our farm stock. The laws which regulate this need to be understood, as well as the peculiarities of the various breeds.

Lastly, if science has done something to point out what is the best course for the farmer to pursue under favourable circumstances, it has also done much to point out the best course under unfavourable circumstances; it has done somcthing to explain and tcach mcn how to amelioratc the diseases of plants and animals; or to prevent the occurrence of disease.

To a great extent, however, the diseases of plants and animals seem, like the diseases of man, to result in no small degree from the state of the weather. Thus the appearance of blight on the hops, of the potato disease, of the rot in sheep, all seem to depend upon the dampness of the season. In fact the greatest difficulty the farmer has to contend with, the one element upon which all farming depends for its success, and that the very element we have least control over, is the weather. Science may do much; skill, industry, capital, may all be expended upon a farm; but, if the weather is not favourable, nothing will make the agricultural return a success. This, however, may be safely asserted—be the weather good or bad, it will always be more advantageous to the farmer who has spent money, time, and skill in a scientific manner, than to him who has ignored the aid which science offers him.

Thus has an attempt been made to show that, whilst science explains the practice of the past, it also foreshadows and will regulate the practice of the future. Science is the handmaid of practice; the two go side by side, yet inseparable. That the most enlightened of agriculturists in England, past and present, believe this to be true is shown by their motto, 'Practice with Science,' and throughout this work that motto will be ever kept in view, while endeavouring to explain the Science of Agriculture.

CHAPTER II.

THE ORIGIN OF SOILS.

If we look at a geological map of Great Britain we find that the surface is coloured by some twenty or more colours, and upon inquiry we shall discover that each of these colours indicates a particular kind of rock. Now, as soils proceed more or less directly from the decomposition of rocks, it is necessary that we first obtain an accurate idea of what these rocks are, and how they have been formed. According to the doctrine now most accepted, this earth was once a molten mass; upon cooling this mass was transformed into, or rather constituted, what we now term rocks. But as only a few of the rocks we are now acquainted with were formed in this manner, whilst others have been formed not by the action of fire, but by the action of water, rocks have been divided into two classes, the one being called 'igneous' and the other 'aqueous' or 'sedimentary.' 'Igneous rocks form but a small proportion of the outer rocks of the world.' Thus, if we examine the geological map of Britain as an example:—in North Wales a considerable proportion, perhaps a twentieth part, of the rocks are formed of igneous masses. 'The whole of the rest of Wales till we come to Pembrokeshire contains scarcely any whatever. The same comparatively small proportion of igneous rocks is found in parts of Scotland and Cumberland, and in even less proportion they also exist in Derbyshire, Northumberland, Devon, and Cornwall. But if we examine all the midland, southern, and eastern parts of England we shall find no igneous rocks whatever.' In spite of their forming so small a proportion of the surface rocks of the earth, the igneous rocks are nevertheless of immense importance, because it is owing to their decomposition that the other rocks have been formed, and hence these other rocks are composed in no small degree of the constituent parts of the igneous rocks. The most important of the igneous rocks are granite, which in some form or another is familiar to us all, and, secondly, the trap rocks, including the greenstones and basalt. These rocks are supposed to constitute the primary crust of the earth, and as we naturally suppose that this crust was fairly uniform in character, being a molten mass originally, we may conclude that this is still the composition of the molten interior of the earth. We have some proof that this is so, for analyses show that the composition of lavas, now or recently ejected from volcanoes, has a strong resemblance to the composition of basalt and trap rocks generally. This has led some to look upon the trap rocks as essentially the primary rock of the earth's crust. However, our object lies not so much in this domain of geology as in the chemistry of these rocks. We find the trap rocks to consist mainly of two minerals, namely, feldspar and hornblende (or augite), and these minerals are composed of the following chemical compounds :—

Analyses of Minerals.

	Hornblende		Mica	Feldspar	
	Without alumina	With alumina	Potash	Potash orthoclase	Soda albite
Soda .	—	3·14	4·10	none	11·47
Alumina .	none	6·31	36·23	17·50	19·43
Manganese oxide	none	1·13	—	—	—
Calcium oxide (lime)	15·06	9·68	·50	1·25	·20
Magnesium oxide	23·92	3·62	·37	none	—
Potash	—	2·65	6·20	12·00	none
Ferrous oxide	2·41	21·72	—	—	—
Ferric oxide	—	6·62	1·34	1·75	—
Silica .	54·71	42·27	44·60	66·75	69·00
Loss on ignition	3·33	·48	5·26	—	—
	99·43	97·62	98·60	98·25	100·10

A very striking difference is noticeable between feldspar, which contains so much potash, or soda, but no lime, and hornblende, which contains considerable quantities of lime and magnesia, but not any potash, nor soda, to speak of. The other igneous rock of most importance is granite. There are many kinds of granite, but they all consist mainly of quartz, feldspar, and mica. Quartz, as you know, is almost pure silica. Mica, on the other hand, is a highly complicated mineral, containing nearly all the compounds found in both feldspar and hornblende: it is said to be, next to feldspar, one of the most abundant minerals. Of the many kinds of granite it may be as well to mention one or two. Any one of the three constituents of common granite may be absent or replaced by another substance. Thus quartz is sometimes absent, and then the compound of feldspar and mica is termed syenite, whilst sometimes the mica is replaced by hornblende, forming a hornblendic granite.

Thus the igneous rocks consist mainly of four elements—quartz, feldspar, hornblende, and mica. From the decomposition of these rocks, and reformation of the decomposed parts, the aqueous rocks have been formed.

In the very earliest periods of this earth's existence rain must certainly have fallen, and had its consequent results. Now what are the results of rain? 'Everyone knows that the rain which falls upon the land, draining the surface, first forms brooks, and that these brooks running into common channels, and joining, by degrees often become rivers; and everyone knows that these rivers are seldom pure and clear, but carry sediment and impurities of various kinds in suspension, or held in solution, and this matter having been derived from the lands through which rivers flow, is carried to lower levels.' Now we have every reason to believe that this had already taken place with the igneous rocks before ever the first sedimentary rock was formed. Experience has proved that rain will dissolve the most soluble parts of the granites—that is to say, the potash and soda salts—and that after so doing the remainder easily crumbles up into small powder. This would be the nature of the first matter carried by the streams to the sea or lakes. We know also from experience that the granites are slightly fertile when broken up into soil, and there is therefore every probability that plant life existed in an early period of the world's history, and this would hasten the decomposition of the rocks. These are agents which we now know of as capable of destroying rocks, and what others there were we may not know;

certain it is that the igneous rocks became destroyed, and washed by streams into lakes or the sea. Here the sediments which they held in suspension were deposited at the bottom, and, constantly increasing, they gradually formed accumulations of more or less thickness, generally arranged in layers or strata.

The property of moving water, and, its action upon solid substances as affecting the formation of these rocks and of soils, has been admirably treated by Professor Sullivan. The transporting power of water depends upon its velocity; according to Hopkins, the law of its progressive increase is as the sixth power of its velocity. Thus, if we double the swiftness of a current, it will move pebbles possessing sixty-four times the weight of those it could have moved before.

The more easily a pebble approaches a sphere, the more easily can it be moved; therefore in running water those rocks which wear into more or less rounded fragments move first, following the order of their density and volume. Those which are flat are moved with most difficulty.

The finest part of all detritus is always lifted, and it is that part which is of most importance in the formation of soils. Now the deposition of solid matter out of suspension in water depends essentially on its form. Thus of several pieces of stone, each of the same volume:—

A	sphere took	3·91	minutes	to settle.
	cube	5·85	,,	,,
	cylinder (short)	6·50	,,	,,
	prism	7·60	,,	,,
	cylinder (long)	10·67	,,	,,

It is evident that if deposition of these substances took place in large seas, there would be a more or less complete separation of the variously-shaped matter. Hence the differences in mechanical and chemical composition of argillaceous (clay) and (arenaceous) sand rocks, or of any sedimentary rock not composed of a single chemical substance. All the aqueous rocks have been formed by deposition in water in this way, or from some other cause, such as precipitation of the matter held in solution by the water; but in whatever way they have been formed they all present the common feature of being in layers, and are hence called stratified. They have been divided by geologists into three groups, named, respectively, primary, secondary, and tertiary. One fact only in connection with these groups must be specially remembered; it is this: The primary rocks were all formed before the secondary, and therefore lie underneath them, and the secondary before the tertiary, and lie underneath them. This we must bear in mind, for it will teach us that, wherever a secondary formation is upon the surface, it will be useless to look for a tertiary underneath it; but it may be possible to find a primary rock there. The especial value of this knowledge to the agriculturist will be pointed out in a future chapter.

The three divisions of stratified rocks contain about eighteen distinct strata, to each of which the geologist has given some special name. The agriculturist in taking a farm should invariably discover what strata lie immediately beneath his surface soil, for by this means he may gain information which will be of immense value to him, apart from the fact that experience shows certain formations to be peculiarly fitted for the growth of certain plants or trees; for example, it is a well-known fact that the best orchards are formed upon the old or new red sandstone formations. These strata are composed of either sandstone, claystone, or limestone. It is easy to understand the reason of this. Streams carrying down sand with them would finally deposit it, the clay being lighter would be carried further on, whilst the lime being in solution would subsequently be deposited in the shells of marine animals; the combined influences of pressure and time would convert these deposits into rocks. It will be well to briefly mention the principal rock formations which come under these three heads of sandstone, claystone, and limestone. There are three principal formations of sandstone: the old red, the new red, and the greenstone. They all derive their colour from iron, the two first from a red oxide, the last from a green silicate.

The old red sandstone, which occurs in Brecknock, Hereford, and part of Monmouth, and also in parts of Scotland and Ireland, forms as a rule rich red soils, though here and there it may crumble into very sandy soils not easily managed with profit.

The new red sandstone comes to the surface throughout nearly the whole of the central plain of England. It is not purely a sandstone, but consists also of marl, which is a mixture of clay and lime, and this is probably the cause of its producing most fertile soils. Moreover, they are not too heavy or clayey, so that the expense of working is moderate, and consequently we find them mostly in arable cultivation. It is not only in England that these soils are fertile—a proof of which may be given in the fact that such soils as a rule fetch a higher rent than those upon any other formation in England—but wherever this formation occurs the soils formed from it are generally of high agricultural value.

The greensand formation consists partly of sandstone, partly also of clay, and partly of sand. The bed is 500 feet thick; one-half of it below consists of sandstone, above this there is a layer of clay, and above this an upper layer of sand. The two layers of sand are respectively called the lower and upper greensand. These formations occur in Surrey and Sussex. The lower sandstone forms poor soils, and the same would probably be the case with the upper greensand were it not for a very exceptional peculiarity which it possesses. In this upper greensand occur nodules of stone like big pebbles, which contain a large quantity of phosphate of lime; now phosphate of lime is a most valuable substance to plants, and the consequence is that these nodules, or 'coprolites' as they are called, have conferred upon the upper greensand a considerable degree of fertility.

The claystone formations.—Of these there are five principal ones, which if arranged according to their age may be classified thus—Lias, Oxford, Kimmeridge, Wealden, and London. These are not all the clays, but they are the principal formations. The claystones have formed a very considerable part of our English soil, and those most difficult to work, and most needing the application and knowledge of science. The lias clay alone, which is an immense deposit of blue clay producing poor soils, reaches from Lyme Regis, the extreme south of Dorsetshire, right through the centre of England up to Yorkshire. The position of the Oxford clay is shown by the name; it occurs, however, in many other counties of England, wherever the middle oolite formation rises to the surface; in fact, it occurs in as many as nine counties of England, where it forms extensive pasture lands.

The Kimmeridge clay occurs in the upper oolite formation, chiefly in Dorset and Wiltshire. The *Weald clay* in the counties of Sussex and Kent. The *London clay* forms those soils so well known to all Londoners which surround us in Middlesex, and is also found in small quantities in Essex and Hampshire.

There is a striking similarity in the soils which are formed from these clay rocks, or deposits, just as in those formed from the sandstones. We all know how clay hardens in dry weather into lumps almost as hard as stone. This peculiarity of clays makes them invariably hard to work, and consequently it is seldom that purely clay soils are found profitable for arable cultivation—that is, for the raising of crops. Consequently the land is laid down to grass, and most of the pasture grounds of England are found upon soils produced from claystone formations.

The limestone formations are best divided into four classes. The oldest is the *mountain limestone* formation. This is a hard blue limestone rock, and produces only very shallow soils. It occurs in the North of England, forming a main portion of the Pennine range of hills. The *magnesian limestone* extends from Durham to Nottingham, and lies immediately below the new red sandstone; whilst the mountain limestone lies immediately above the old red sandstone. The magnesian limestone is said to yield soils very nearly barren, but this may partly be due to the great height above the sea of many of these soils. The *oolitic limestone*, or Bath stone, is very characteristic and easily crumbles, consequently it forms better soils than those of either of the two previous formations. Limestone is also found in the upper oolite beds.

The chalk formation lies below the London clay, and is dug into to find the water which makes much of the London ale and stout. The chalk is peculiar from the number of flints which are found in it. Some of the soils upon this formation are capable of growing corn, but they are not rich soils, and where chalk prevails there probably are the lowest rented English farms to be found. If the soils lying upon the claystones were not used for arable cultivation, the same may more truly be said of those soils which lie upon the limestone formations. As a rule, they only produce very thin soils, which would not repay the expense of arable cultivation; they are therefore allowed to grow the grass which they will bear naturally This, though small, is peculiarly sweet, and upon it vast numbers of sheep are turned out to feed. These lands form 'downs' in different parts of England, and most of us know of the South downs from the sheep which take the name of their feeding grounds.

The formation of soils.—Such are the rocks from which soils are formed, and it is evident that the nature of the soil will be influenced by its parent rock. What are the forces of nature which combined have resulted in the formation of these soils?

Firstly, weathering.—Owing to the immense disturbances the primary rocks were originally subject to, we find that these, and also the sedimentary rocks, are more or less covered by fissures. If these fissures be in certain directions they become filled in wet weather with water, and should a frost ensue rapidly, the freezing of the water will cause it to expand, and the force of the expansion of the water will more or less increase the crevice in the rock, or it may sever a piece completely off. Thus, immense masses of rock become detached as well as small pieces, and are exposed to the influence of the weather. This action of freezing water—apparently so trifling—becomes in the aggregate immense. It is evident that it depends upon variations in temperature, *i.e.* upon climate, and that where no frost is, the action will be slight, as also where there is continual frost. Consequently in hot climates, the soil, owing to the luxuriant vegetation, will be rich in vegetable matter, and poor in mineral matter; while in cold regions, the soil will be poor in organic matter, and likewise of no depth.

The next property of water, that of finding the lowest level, will cause it to flow in little streams, gradually increasing until it may reach the sea as a river. In its course it will carry with it fragments of rock that have been broken off, and by rolling these against one another, break them up continually into smaller pieces. A similar action is exerted by glaciers, which in the past history of England have exerted very considerable influence in breaking down the rocks, and in otherwise transforming the surface of the land. It is even said, that most of our lakes have been scooped out in past ages by the action of glaciers.

Apart from its mechanical action as water or ice, water also exerts a twofold chemical action. Firstly, it is a solvent of many of the constituents of rocks. By dissolving these out, it leaves the surface of the rock more or less pitted. These little holes become filled with water, which, freezing, break the surface of the rock into fragments, and if the water has but little flow over the rock, these minute particles will remain and subsequently form a soil.

But the most powerful action of water upon rocks is due to its property of dissolving carbonic acid gas, which in its turn acts upon substances that would not otherwise have been dissolved, more especially upon lime, and which consequently helps in the formation of soils upon limestone rocks, for part only of the rock will be dissolved, while much will be split up into fragments by the action of frost and constitute a soil. Lime, however, is not the only substance which yields to the action of carbonic acid, for iron is likewise dissolved by it in considerable quantity; and it combines with the potash and soda of feldspar, causing the decomposition of this mineral. Rain water also contains oxygen; this exerts a powerful influence upon some salts of iron; hence all rocks which, like hornblende, contain ferrous oxide are acted upon by oxygen, the oxygen converts the green ferrous oxide into red ferric oxide, and brings about the disintegration of the rock. Thus there are four agents—ice, water, carbonic acid, and oxygen—continually at work in disintegrating rocks, and soils having had innumerable years to form, we can understand how these apparently slow-acting agents have produced such enormous results. The conjoined influence of these forces of water and gases upon the rocks is called 'weathering.' Besides these forces there are still others.

Secondly, plant life.—We know from experience that plants of a low order, such as lichen, will grow on the bare surface of the rock. These by their decay will form a small film upon the rock and aid further vegetable growth. That such growth existed, in immense quantity, at an early stage of the earth's history, is evident from the coal beds which are distributed over the face of the world, for coal is the remains of plants. We know that the plant has considerable action upon rocks—so much so, indeed, that if a plant be grown on a slab of rock, and kept well watered, the roots spreading over the surface of the stone will eat into it wherever they go, and leave a facsimile of their every ramification. Thus, vegetable growth would disintegrate the rock. But it does more, it helps to bind together the disintegrated particles, and so keep the soil which it has formed from being washed away; moreover, upon the decay of the vegetable matter in the soil, carbonic acid would be given off, and this would act as a further pulveriser of the rock particles.

Thirdly, animal life.—Of the many investigations which were made by Darwin, none perhaps is more interesting to the farmer than that upon worms. Darwin has proved, beyond a doubt, that worms play a very important part, if not in the formation of our soils, at least in their amelioration. It will be worth while to briefly sketch some of the results of his observations which we may ourselves observe if we will but look for them. We all know what a worm is, that it has the power of burying itself, by burrowing holes in the soil, and that it is capable of doing this even in soils so thick that they can only be cut with difficulty by a knife. The passages are formed by the worms by the combined actions of pushing aside the earth, and also of swallowing it. The swallowed earth undergoes a partial chemical reaction in the stomach, or alimentary canal, and is then voided. But not only do worms swallow sufficient earth to make their burrows, but it is also certain that 'they swallow a larger quantity of earth for the sake of extracting any nutritious matter which it may contain.' After swallowing earth, whether for making its burrow or for food, the worm soon comes to the surface to empty its body. The ejected earth is thoroughly mingled with the intestinal secretions, and is thus rendered viscid. When dried it sets hard, and forms the castings which may generally be seen at the mouth of any worm burrow, and which are plentiful upon most garden paths. Nevertheless, worms do not always eject their castings upon the surface, but sometimes in holes or cavities in the earth. Besides ejecting this earth round the tops of their burrows, worms seize leaves and other objects, and with them plug up the mouths of their burrows; this is one of their strongest habits.

The action of a worm in bringing up fine soil to the surface, however slight, becomes considerable when performed by numbers, and spread over long periods of time. In one instance, mould to the thickness of one-fifth of an inch has been annually brought up by the worms, and many other instances have been noted where close upon the same quantity of mould has thus been deposited upon the surface. Thus, in process of time, the whole surface will become reconstructed, and what had originally been at the top will then be buried. It is probably due to this cause that we find stones continually sinking in the soil. Every farmer knows that lime placed on the surface of a soil gradually sinks down into it, where many years afterwards it may still be found in a more or less continuous layer, and probably worms have helped to effect this. The earth brought up by worms and cast on the surface is very fine; it has also undergone chemical treatment, and is probably much richer in organic matter than the natural soil. The quantity which thus becomes treated is not insignificant. It is certain that in some parts of England, upon every acre of land, no less than ten tons of dry earth annually passes through the bodies of worms and is brought to the surface; so that the whole superficial bed of vegetable mould passes through their bodies in the course of every few years. Thus we see that worms prepare the ground in an excellent manner for the growth of plants. They periodically expose the mould to the air, and sift it, so that no stones larger than the particles which they can swallow are left in it. They drag an infinite number of dead leaves into their burrows, tearing them into shreds, partially digesting them, and converting them into rich humus. These burrows, penetrating the ground to great depths, materially aid in its drainage, they allow the air to penetrate deeply into the ground, and facilitate the downward passage of roots of moderate size; moreover, these roots will be nourished by the humus with which the burrows are lined. Thus, long before the plough, which is one of the most ancient and most valuable of man's inventions, existed, the land was regularly improved, as it still continues to be improved, by earth-worms.

Soils.—These various methods by which soils have been formed from the rocks have resulted in the formation of different kinds of soil, generally classed as *sedentary* and *transported.*

Sedentary soils are those formed by the decomposition of the underlying rock, and partake, therefore, of its nature and composition, except in the probable addition of organic matter. Such soils have seldom any great depth, and their nature and use can be approximately judged from the kind of rock underlying them. Examples of such soils are found upon the old and new red sandstone formations, on the oolite and chalk, and on the Oxford, Weald, and lias clays. Whilst some are fertile, many such soils, like the sedentary soils on the clays and on the limestone formations, are poor and scarcely capable of cultivation. Where, then, do the soils come from that are capable of cultivation? A very important fact will partially answer this question. Whenever two geological formations meet, and the soil is consequently composed of a mixture of the soils formed from these rocks, that soil is invariably more productive than the soil on either of the formations separately. The geological formations in England being numerous, this mixing consequently occurs frequently, which partially explains why there is so much good arable soil. Thus, for instance, the clay in the greensand is most unproductive; where, however, it mixes with the chalk an improved soil is obtained, well adapted for the growth of barley. Where the clay comes in contact with the mountain limestone good oat soils are formed, and in places good wheat soils. These are merely typical examples of what occurs all over England. The mixed soils, however, are not confined to the few sedentary mixed soils just mentioned; they constitute the main portion of the second class of soils, which are termed transported.

Transported soils have been deposited from water or ice. The former are termed *alluvial* and the latter *drift* soils.

Alluvial soils.—These soils occur not merely at the mouths of large rivers, such as the Nile, where the soil is entirely alluvial, but also in inland places where they have been deposited in lakes, now dried up. In England alluvial soils are found in several parts. The alluvial flats of Cambridgeshire, Lincolnshire, and the Wash—the latter a vast plain which has been and still is the recipient of the mud of several rivers—are typical examples.

Drift soils.—A glacier is a moving mass of ice, like a frozen river still flowing. It carries with it immense pieces of rock as well as vast quantities of earth, and these are subsequently deposited wherever the glacier melts. The deposits are known as glacial drift, or drift, and by their subsequent weathering give rise to drift soils. There can be no doubt that Great Britain has in past ages passed through a glacial period. Abundant signs of it are found in most parts of the land, not merely in the high mountains, but in the valleys also, as shown by the effect which those glaciers have had in wearing the surface of the rocks. The immense boulders which are found here and there in Great Britain, composed of stone, which does not exist within some hundred miles or so of the spot where the mass now lies, also point to the previous existence of glaciers. But not merely have individual masses of rock been deposited here and there from the snow or ice, though these are the most striking, but there have been immense deposits of earth and stones of more or less fineness of division. These deposits have considerably modified the soils of Great Britain, and for the most part improved them.

Thus we find that where the ground is high it is to a great extent untilled; 'where, however, the slopes descend, and are covered more or less with old ice drifts and moraine matter, the soil is deep and the ground is fertile.' The deposited matter has sometimes been subsequently affected by marine action, and the result of the 'rearrangement of the ice-borne *débris* has been to cover large tracts of country with a happy mixture of materials, such as clay, mixed with pebbles, sand and lime. In this way one of the most fertile tracts anywhere to be found in our island, the Carse of Gowrie, has been formed, and its cultivation for nearly a century has been taken in hand by skilful farmers, who have brought the agriculture of that district up to the very highest pitch which it has attained in any part of Great Britain.' The reason of the fertility of drift soils must be looked to as chiefly due to the bringing together of a variety of soil constituents. Thus, in South Wales, we find lying upon the old red sandstone an unfertile drift, forming fertile soils, having become mingled with the waste of the partly calcareous strata upon which it rests, and the rocks of which are generally soft and easily decomposed.

The drift is not uniformly spread over the island. In some parts it is absent, in others it forms a thick covering to the underlying strata. Through the greater part of the lower country north of the Thames and the estuary of the Severn, there is a widespread covering of drift, which much obscures the main rock masses. The importance of the drift covering is nowhere more apparent than in the eastern counties (Norfolk, Suffolk, and Essex). The drift is chiefly of two kinds: a clay containing many fragments of chalk (boulder clay); and sands or gravels. The stiffest clays are sometimes covered by thick and widespread sheets of gravel or sand, whilst the calcareous or sandy rocks may be covered by clay. Clay drift over clay, or sand drift over sand or limestone, has a less striking but often a not less important influence in modifying the agricultural features of a country.

Thus it will be seen that in Great Britain the soil is partly sedentary, partly alluvial, and partly drift. Unfortunately, there is yet no geological map of the surface, and hence, owing to the prevalence of transported soils, an ordinary geological map is of little use to the farmer.

CHAPTER III.

COMPOSITION OF SOILS.

General examination of a soil.—The soil may be considered in two ways: firstly, as a mass of particles of matter, which mass has certain physical properties; and secondly, as a mixture of substances, each having certain chemical properties. According as the properties of a soil are due to its physical formation or chemical composition, so these properties are distinguished as physical or chemical.

If a block of soil, some 6 inches square and 9 inches deep, be dug out of a field, it will serve to illustrate all the peculiarities of the soil. Let this portion of soil be dried and broken up by the hands, and it will be found to contain many stones, some large, some small. By a series of sieves, these stones might be separated according to their various sizes, until only a very fine earth was left. This earth might be again separated by washing, that is, by mixing with water, allowing to stand a moment or two, when the heavy and larger sandy particles fall to the bottom of the vessel, the lighter remain in suspension and may be poured off. This lighter portion consists of clay. Such a separation of the constituents of a soil is termed a mechanical analysis. Various kinds of apparatus have been devised to further separate this fine matter into four or more distinct portions, the apparatus of Noebel being mostly used. No practical conclusions, however, can be drawn from the information about a soil which this mechanical separation or analysis gives. The only result of any importance is, that it indicates and separates the silica which exists as clay, and the silica which exists as sand; a distinction which is not shown by an ordinary chemical analysis, where both kinds of silica are classed together. It is generally possible, however, to tell from the mere texture of a soil whether it contains much clay or little.

In continuing the examination of the soil, if it contains large lumps of stone these may be dispensed with, because, no matter what their composition, they will not immediately affect the chemical composition of the soil. It must not be supposed, however, that they are useless in the field—often it is far otherwise. There are some soils, in the West of England for instance, where the surface is covered with stones, many much larger than a man's fist. These soils are most productive and yield excellent crops. One of the farmers, however, thinking to improve the soil and make it easier and better to work, carted off the larger stones. So great was the effect of this upon the land, that he could get no good crop, and so soon as possible he carted the stones back to the field. Thus, it is often the case, that what may not affect the chemical composition of the soil, may yet have very striking influence upon it, by affecting its physical properties.

By close inspection, and with a little care, it is possible to find out what rock these pebbles and stones have been derived from; and it may be concluded, with some degree of certainty, that the fine soil will partake to a great extent of the nature of the larger pieces. Thus, if they consist of feldspar, the soil will probably contain a good supply of potash; if they consist of limestone, it may be inferred that lime will be abundant in the soil; while if they are quartz, the soil may naturally be expected to prove of poor quality. Moreover, as these stones by their weathering will constantly supply fresh matter to the soil, it is possible to determine whether this is likely to prove useful, and also its special nature.

If the soil upon drying easily crumbles down into fine particles, having the characteristic appearance of sand, the soil will be a *sandy* soil. The fact of its consisting of sand will indicate many of its physical properties, which will be described in a future chapter. One point specially should be noticed—whether the particles of sand be large or small—because the smaller the particles, the more chance will there be of the soil being fertile. Should the soil consist of *clay*, it will dry into a hard mass, which it is almost—or quite—impossible to break up with the hands alone; if, however, the clay be mixed with sand or lime, then, although drying into lumps, these will be more easily broken up than a true clay, and will constitute what is termed a *loam*. Soils which contain lime in considerable abundance are termed *calcareous*, and may be known by their light colour. The presence of lime in a soil is easily detected, whether it be present in the form of lumps, or as an impalpable powder. It invariably exists in the soil, as carbonate of lime, and this substance, when brought into contact with strong or mineral acids, gives off its carbonic acid in the form of a gas, causing effervescence. As the presence of lime in a soil is of great advantage, it is advisable that every farmer should know how to test his soils for it. The best way is to put a little of the soil, or a lump of the stone, one wishes to examine in a saucer, mix it with water very thoroughly, so as to get all the air expelled from the pores of the soil, and then add a little hydrochloric acid; if lime be present an effervescence at once commences, its extent and duration depending upon the quantity of lime present. Only one other substance likely or capable of being present would cause this effervescence, that is a sulphide, such as sulphide of iron. If such were present, a gas of a most disagreeable odour would be given off, and would yield very important information in regard to the soil, of which hereafter. The general examination of a soil will show, lastly, whether it consists of or contains much *organic matter*, such as the roots of plants or peat.

Thus, by a careful, though very simple, examination of a soil it is possible to obtain a large amount of information. If this be supplemented by a chemical examination, then the present and future possibilities of the soil can be accurately estimated.

The chemical examination of a soil is required to determine not merely what are the chemical constituents the soil contains, but also whether the constituents are in a form assimilable by the plant or not; and, further, whether the soil contains any matter injurious to vegetation. Those compounds in a soil which are immediately available as plant food have been termed the *active* constituents, and those not at present available, but which will become so, the *dormant* constituents. The great difficulty, however, is to distinguish between these two with any degree of accuracy. It has been shown that the roots of plants, if passing over a stone, will, as a rule, leave their mark upon that stone in the form of a slight indentation, which has evidently been eaten away by the roots as they grew. This could not be done by water, which would fail to dissolve the stone. It is also known that phosphoric acid exists in soils in forms easily assimilable to the roots of plants, but nevertheless not dissolved to any appreciable extent by water. It is evident, therefore, that the quantity of soil soluble in water is not an accurate estimation of the plant food in that soil. In fact, it is found that soils containing a large quantity of matter soluble in water are absolutely injurious to plant growth. No other solvent has yet been found capable of accurately representing the amount of action exercised by the roots of plants; consequently the customary practice is to estimate the composition of the portions soluble and insoluble in hydrochloric acid, and to look upon the soluble portion as capable of being utilised by the plant at once, the insoluble portion as a reserve fund to be utilised in the future. Thus the portion soluble in acid is termed the active portion, the portion insoluble in acid the dormant portion. It is evident, however, that this is only an approximation to the truth.

Every soil upon which plants have grown will retain a certain proportion of the roots of these plants, intimately mixed up within them, and more or less decayed. The action of worms also, as already pointed out, will have incorporated with the soil the matter of dead leaves; hence every soil contains more or less organic matter. Organic matter may be generally described as consisting of that part of vegetable and animal bodies which is dissipated, or burnt away, at a red heat. By making use of this knowledge it is easy to estimate the amount of organic matter in a soil, by simply heating a weighed quantity to redness and weighing the remainder; the loss will give the organic matter. The residue will be mineral matter, which, as just described, consists of two portions, the one soluble and the other insoluble in hydrochloric acid. It will now be necessary to describe in detail, so far as is practicable, the nature of these three portions of a soil: the organic constituents, the soluble mineral constituents, and the insoluble mineral constituents.

The organic constituents.—Many attempts have been made to discover the nature of the organic matter in the soil, but still little is known about it. By contact with the soil, insoluble organic matters become decomposed and formed into more or less soluble matters, of a dark-brown or even black colour, called collectively, *humus.* The changes in the organic matters which pass into the soil are apparently due to continuous but slow oxidation. Humus is the result of this oxidation. Recent researches point to the change being produced by some fermenting action; it may, however, be that worms are the chief cause of this change. Suffice it to say, that the result of this oxidation is to form substances which possess an acid reaction—hence called organic acids; and chemists have been able to isolate from humus four or five such acids, of which the principal are called humic acid and ulmic acid. These substances are soluble in slightly alkaline solutions, and give them a dark-brown colour; they are precipitated from the alkaline solution if it be made acid.

Even if humus is a very indefinite term, it does service until more is known about this organic matter. For although its actual nature is indefinite, yet it plays a most important part in the soil, conferring upon it qualities which may under certain conditions prove beneficial, under other conditions injurious. Like most organic matter, humus consists chiefly of carbon. Upon its complete oxidation and decomposition this carbon takes the form of carbonic acid gas, which, permeating the interstices of the soil, becomes dissolved in the water in the soil, and renders this water capable of decomposing more of the mineral matter than it would have been able to otherwise.

The other constituents of humus are of little value, save one, *nitrogen.* Nearly all organic matter contains nitrogen, and it is an essential constituent of plant and animal life, consequently its presence in the soil is of primary importance. Although it is present in minute quantities, usually under ·2 per cent., yet it plays an important part in regulating the fertility of a soil. The soil also contains nitrogen combined with oxygen to form nitric acid. This is dissipated upon heating the soil, as well as the nitrogen contained in the organic matter. The other properties of organic matter affect chiefly the physical peculiarities of the soil, and will be treated of further on.

The amount of organic matter found in different soils varies greatly, but does not appear to influence the fertility of the soils of different localities. Thus, it is said, oats will grow upon land containing only two per cent. of organic matter, barley on land containing three per cent., and wheat on land containing four per cent., while the alluvial soils of the Nile contain only five per cent. Many soils, however, contain as much as ten per cent., while peat soils and rich vegetable moulds contain, of course, far more.

Whilst the fertility of soils in different localities is not much influenced by the quantity of organic matter they contain, on the other hand the fertility of soils from the same locality, of otherwise similar composition, and subject to the same climatic influences, varies considerably according to the amount of organic matter present.

The method here given of estimating the organic matter in a soil, viz. by burning, is subject to one great drawback. For instance, if a clay soil be treated in this manner the loss will be considerable. This loss is not organic matter, however, but mainly water of combination; that is, water in combination with certain chemical compounds, probably clay, which is not driven off at the temperature of boiling water, but is driven off at the high temperature to which the soil is raised to estimate the organic matter. This error has led some to the erroneous belief that clays as a rule contain as much as ten to twelve per cent. of organic matter; a quantity which would be most exceptional. The portion not dissipated by heat is termed in contradistinction the in-organic portion, or mineral matter.

The soluble mineral constituents include all the essential and valuable constituents of the soil, especially lime, potash, and phosphoric acid. These three form the principal mineral foods of the plant, and therefore if a soil be deficient in either, it is, chemically speaking, a poor soil. The substances which form the bulk of the soluble portion of a soil are iron and alumina. Every soil contains iron and alumina, present as a rule in nearly equal proportions, the iron being a little in excess of the alumina. In some few soils, however, such as the sugar and coffee soils of the tropics, alumina is considerably in excess of the iron. The presence of iron in soils is but natural, considering how universally it is spread over the surface of the earth, and how large a part it forms of the primary minerals of the earth's crust, the rocks. Alumina comes from clay, which is a silicate of alumina; hence clay soils always contain a large proportion of alumina. The total quantity of iron and alumina in a soil will rarely amount to fifteen per cent.; as a rule from six to thirteen per cent. will be found, of which four to seven parts will be oxide of iron, the remainder alumina. Iron and alumina are not of much value as plant food, yet their presence in a soil is of importance, owing to the physical and chemical properties they bestow upon it.

Next to iron and alumina, carbonate of lime forms the most abundant soluble substance in a soil. In purely calcareous soils it may form the main portion of the whole soil, and constitute over fifty per cent. thereof. On the other hand it may dwindle down until in some soils it reaches only one-tenth of one per cent. As, however, carbonate of lime is one of the three essential mineral constituents of plants, it is absolutely necessary that every soil should contain it, and if not present in quantities of over one per cent., or better, two per cent., it will be necessary to add lime to the soil.

Partial analysis of a soil.—An analysis of a soil which shows the quantity of these substances, organic matter, oxides of iron and alumina, and lime, as well as the quantity of insoluble mineral matter, is called a partial analysis. The following may be taken as examples :—

Partial Analyses of Soils.

	Clay	Sandy loam	Clay	Sandy.
Organic matter and water of combination	7·90	9·71	5·28	2·44
Oxides of iron and alumina	7·10	1·44	9·40	3·80
Carbonate of lime	·19	·12	3·46	1·56
Magnesia, potash, soda, &c.	·74	·07	—	—
Insoluble mineral matter	84·07	88·66	81·86	92·20
	100·00	100·00	100·00	100·00

The first two show a deficiency in lime, and will never be truly fertile until lime has been added ; the second two possess sufficient lime, and to add more would be waste of money. It would seem unlikely that farmers should desire to add lime to soils such as the last two. If they knew what their soils contained, it may be presumed they would not ; but the majority of farmers are perfectly ignorant of the composition of the soils they cultivate, and cases are by no means unfrequent where farmers have at a considerable expense added lime to land which has proved upon analysis to have required no lime whatever. A partial analysis of a soil shows a farmer whether his land has a sufficient quantity of lime or not.

Complete analysis of a soil.—This will reveal the amount of those soluble mineral substances which generally exist only in minute quantities, the most important being phosphoric acid and potash. Phosphoric acid is very seldom present in a soil to the extent of ·5 per cent., more usually ·2 per cent. is found in rich soils, while in poor soils it dwindles to less than 1 per cent. The quantity of potash in a soil sometimes amounts to two or three parts per cent., but as a rule is under half of one per cent., and in poor sandy soils may be less than a tenth. Clay soils are usually rich in potash, which exists combined with the silicate of alumina in the same way as it exists in feldspar.

Magnesia is found in all soils to a small extent, seldom amounting to one per cent. Wherever lime is present, there magnesia is sure to be found also. It has not been shown that magnesia plays any important part in the composition of a soil, nor yet in its physical properties. Three more substances are found in minute quantities in the soluble mineral portion of soils—chlorine, sodium, and sulphuric acid. Chlorine when present is generally combined with sodium to form common salt, and rarely exceeds 1–100th part of one per cent., for owing to its extreme solubility in water it is rapidly washed out of the soil by the rain. Sodium also exists in the soil but only in very small quantity, amounting, for the most part, to less than one-tenth of one per cent. Sulphuric acid is present in all fertile soils in small quantity. It is undoubtedly an essential constituent, more especially for the growth of crops like mustard and clover, which contain a considerable proportion of sulphur. It is generally found that where there is a sufficiency of lime there is also a sufficiency of sulphuric acid.

One other substance is found in soils in varying quantities, namely, *soluble silica* ; as a rule the amount present is less than one per cent. It is not possible to state with certainty how it exists, though it is probably present as a soluble silicate of alumina. It is not known to play any important part in regulating the fertility of the soil, hence it is seldom taken notice of in analyses, being classed with the insoluble portion, which is mostly silica. Such is the quantity and the nature of the different chemical substances found in the soluble part of soils.

It is evident that sulphuric acid and phosphoric acid do not exist in a free, or acid, condition, but that they are combined with some substances to form compounds. What these compounds are it is not possible in the present state of our knowledge to say with certainty. Both the sulphuric acid and phosphoric acid are probably combined with lime or magnesia. The remainder of the lime and magnesia will exist in combination with carbonic acid. Any chlorine present will be combined with sodium. The remainder of the sodium and also the potash will probably exist as carbonates, that is, in combination with carbonic acid. Iron probably exists as oxide or hydrated oxide, and a small portion as carbonate. The organic acids of humus are generally combined with bases, such as ammonia, potash, or lime, or even in some instances with iron. These combinations cannot be said with certainty to exist, but there is great probability of their existence, and they explain the properties of soils so far as they are at present understood.

Now with regard to alumina, how does this exist? It is probable that the alumina in a soil exists as silicate. There are two kinds of silicate: a simple silicate, which is a combination of silica with one base, such as alumina, and a double silicate, which is a combination of silica with two bases, such as alumina and potash. Of these double silicates, three are of importance, the one having alumina and ammonia, the second alumina and potash, and the third alumina and lime, combined respectively with silica. These double silicates play important parts in giving to the soil certain chemical and physical properties, which will be explained in a future chapter. The double silicates are probably due to the action of the alkaline bases on the ordinary silicate of alumina. Thus has been illustrated the minute composition of soils so far as their soluble mineral constituents are concerned.

The insoluble mineral constituents of the soil are generally termed the silicious compounds. They vary in quantity from 10 per cent. in peat soils, and 30 per cent. in calcareous soils containing large quantities of lime, to 95 per cent., or a little more, in very sandy and unfertile soils. As a rule the insoluble mineral matters amount to between 70 and 90 per cent. of the dry soil. The insoluble silicious compounds are capable of being broken up by fusion with an alkali at a high temperature, and it then becomes possible to discover of what these insoluble silicates are composed.

The knowledge thus gained is of value, because the slow but powerful action of the weathering of the soil will by degrees bring about in the field the same result as is accomplished by fusion in the laboratory. If, therefore, these silicates consist of substances useful to the plant, the soil will yearly gain a small supply of soluble and fertilising compounds. It is to this cause that soils will yield year after year small crops without the land becoming altogether deprived of the substances taken up by the plant. Insoluble silicates contain for the most part pure quartz, or, chemically speaking, silica. They further contain very small quantities of iron, alumina, lime, magnesia, potash, and soda—six of the nine substances which are found in the soluble part of the soil.

Analyses of soils.—Some analyses of soils showing their complete composition may now be taken to see what information they give about the soils, and to illustrate the preceding remarks.

The first three soils belong to Mr. John Prout, whose name is well known. His farm is situated at Sawbridgeworth, in Hertfordshire. The land consists of clay and strong loam, lying upon a subsoil of drift clay and cretaceous gravel. After Mr. Prout had drained the land, improved its condition by the use of manures, and grown many crops of wheat, the soils were analysed by Dr. Voelcker with these results.

The chemical analyses of these soils, coupled with the information which a careful examination would have yielded, would indicate at once that they were rich soils, and valuable for growing crops. A careful consideration of the figures will also enable one to

Complete Analyses of Soils.

	No. I.	No. II.	No. III.	No. IV.	No. V.	No. V. 18 to 27 in. deep
*Organic matter and water of combination	5·033	6·344	4·200	8·858	3·450	1·550
Oxide of iron	5·200	5·312	3·659	6·350	4·001	3·201
Alumina	3·400	4·560	4·100	3·430	·649	·449
Lime .	1·360	3·312	·670	·484	·431	·151
Magnesia	·400	·432	·266	·466	·225	·201
Potassium oxide	·365	·468	·320	·333	·282	·253
Sodium oxide	·121	·179	·031	·092	·069	·023
Phosphoric acid .	·141	·204	·141	·217	·217	·141
Carbonic acid	·875	1·640	·380	—	—	—
Sulphuric acid	·060	·109	·061	·137	·130	·089
Nitric acid .	·001	·001	·001	·002	·008	·002
Chlorine .	·005	·011	·002	·005	·007	·004
†Insoluble silicates and sand	83·066	77·401	86·232	79·733	90·675	93·925
	100·027	99·973	100·063	100·107	100·144	99·989
†Consisting of:						
Oxide of iron	1·827	1·625	·763	1·594	} 1·995	2·723
Alumina	6·188	4·489	6·607	1·897		
Lime .	·511	·774	·638	·558	·553	·732
Magnesia .	·388	·332	·167	·223	·126	·131
Potash	·424	·518	·182	·358	·399	·197
Soda .	·920	·534	·304	1·012	1·242	·779
Silica .	72·848	69·273	77·626	74·091	86·360	89·363
	83·106	77·545	86·287	79·733	90·675	93·925
*Containing: Nitrogen	·170	·107	·141	·254	·101	·050

distinguish between the three, and to decide which is the best. Firstly, the organic matter and water of combination. Upon noting the quantity of nitrogen this contains, it is seen that No. II., although possessing more organic matter and water of combination than No. I. or No. III., contains less nitrogen than either; this illustrates the effect of water of combination, for in all probability the amount of organic matter is in direct proportion to the amount of nitrogen. Secondly, the soluble mineral constituents. It will be seen that the quantities of each substance come within the limits previously pointed out, and further that there is a sufficiency of each constituent, none being present in very minute quantities. Of the three primarily important constituents, lime, potash, and phosphoric acid, soil No. II. contains more of each than either of the other soils, and is evidently the richest, whilst No. I. is better than No. III. Nevertheless No. III. is a good soil, as will be better seen when the composition of poor soils is examined. Passing now to the composition of the insoluble silicates, it will be noticed that the better the soil the lower the quantity of these present. This cannot be said to be an invariable rule, though a fairly general one, except in the case of peat soils and of purely calcareous soils. The analyses of these insoluble silicates will explain why fertility is gained by the soil from their decomposition or weathering, and it will be noticed that the richest soil has the richest silicates, or those containing most lime and potash.

The two other soils come from Bedfordshire, and may be described—No. IV as a loamy soil, from which very good crops of turnips have been taken, and No. V. as a light sandy or gravelly soil, which is suited for the growth of barley.

Upon comparing these analyses with those already examined, many differences may be noted. The first is the high percentage of organic matter in soil No. IV with its correspondingly high proportion of nitrogen. In soil No. V the nitrogen is much less; but there is present a high proportion of nitric acid.

This is probably owing to the oxidising effect of sandy soils upon organic matter. The high proportion of alumina in No. IV shows at once the presence of clay and the cause of its being so stiff, somewhat like the soils Nos. I., II., and III. In the sandy soil No. V. there is far less alumina, although the proportion of iron is still high. Iron is nearly always associated with sand. There are sandy subsoils which contain less than two per cent. of alumina, yet have eleven per cent. of oxide of iron. The lime in IV and V. falls far short of the quantity present in the first three soils. The immense difference between the two soils IV and V is best seen in the quantity of silicates. The high proportion present in No. V points at once to its sandy nature. The small quantity present in No. IV indicates either a clay, a calcareous, or a vegetable soil; which of these is at once shown by the rest of the analysis, in this instance the presence of alumina indicating clay.

The composition of the silicates explains why from the decomposition of the one, with its high proportion of alumina, a clay soil has been formed, and from the decomposition of the other a sandy soil.

The analysis of these soils is the analysis of the first 9 inches in depth. The first 9 inches of soil are usually termed the surface soil. The second 9 inches may be said to constitute the subsoil, so far as the chemistry of the soil is concerned. The word subsoil, however, as its derivation indicates, generally refers to all the soil lying below the 9 inches of surface soil.

In one of these soils, analyses were made of the subsoil, every 9 inches of subsoil being analysed separately. The analysis of the third 9 inches of No. V is given in the table, and it shows some important points in regard to the composition of subsoils. A glance will show how far less rich in soluble constituents this subsoil is than the surface soil lying above it. The lime is less than half. The phosphoric acid and the nitric acid are both present in much smaller quantities than in the surface soil, and finally, the organic matter is only half that of the surface soil, and contains only half as much nitrogen.

Now it will be seen in a subsequent chapter that it is sometimes the custom to bring the subsoil of a field to the surface. In some cases this may be advisable; the subsoil enriches the top-soil and materially improves it. But it is evident that if this were done in the field from which No. V soil was taken, instead of improving the top-soil it would deteriorate it. Whether, therefore, it is possible to bring the subsoil to the surface with advantage can only be decided, provided the farmer knows the composition of both his surface soil and subsoil.

Thus has been shown of what substances a soil is composed, how these vary in different kinds of soil, and the limits within which they vary. It must have been noticeable how small the quantities were of many of the important constituents even in fertile soils; in fact, the quantity of these substances essential to a fertile soil is so small when calculated in parts per 100, as stated in an analysis, that it is difficult to realise the quantity actually existing in a field. These quantities are anything but insignificant. Take the complete analyses of Mr. Prout's three fields. 'Numerous weighings of soil similar to these show that a piece of soil, 1 foot square and 6 inches deep, weighs from 60 to 63 lbs. in its natural moist condition, or about 50 lbs. in a perfectly dry state.' Thus, calculated per acre, 6 inches of clay soil in a dry state weigh 2½ millions of pounds per acre approximately, or more than 1,000 tons. Supposing that the soil weighed 1,000 tons, then the amount of the more important soil constituents the three fields contain per acre, in a depth of only 6 inches, and in a readily available form, are as follows:—

Soil Constituents per acre.

	I.	II.	I I.
	lbs.	lbs.	lbs.
Phosphoric acid.	3,158	4,569	3,158
Potash	8,176	10,483	7,168
Lime.	30,464	74,188	15,052
Magnesia	8,960	9,676	5,947
Sulphuric acid	1,344	4,569	1,366
Nitric acid	22	22	22
Nitrogen	3,808	2,397	3,158

A thoroughly fertile soil, such as any of these, contains, therefore, as much, in fact more, of the principal constituents of plant food than would be required by 100 crops of wheat or barley.

CHAPTER IV

THE PHYSICAL PROPERTIES OF SOILS.

A SUBJECT of every-day observance is that soils present very different appearances. It is even possible by merely looking at a soil to say whether it is a sandy, clay, peaty, or chalk soil. The differences in appearance are partly due to colour, partly to minuteness of structure, partly to the power of the soil to hold together—or what is known as its power of cohesion. Thus the particles of a sandy soil do not cohere, while those of a clay soil hold together with some tenacity.

These are illustrations of differences due to the physical nature of soils. Whatever peculiar properties these differences confer upon the soil are termed the physical properties of the soil. They are dependent partly upon the chemical composition of a soil, being in such case the aggregate of the physical properties of the elementary constituents of the soil.

Weight of soils.—In the last chapter the analyses of soils were given in parts per 100, or what is termed the percentage composition—that is, every 100 lbs. weight of soil contains so many pounds' or parts of pound's weight of certain substances. Supposing two soils from different fields do not weigh equally heavy, bulk for bulk, but that one is lighter than the other, the heavier soil, although it may contain proportionately less of a certain constituent —say phosphoric acid—than the light soil, may really be richer in that substance than the light soil, which apparently contains more.

For example, suppose any soil weighs twice as much as another, bulk for bulk, and that the heavier soil contains only one half the quantity of phosphoric acid present in the light soil. The fields from which the soils are taken will be equally rich, because there will be double the weight of soil in the one field which there is in the other. Soils do thus vary in weight. It is estimated that when dry, a cubic foot of

Sand weighs from	110 to 120 lbs.
Loam (or arable land)	90 ,, 100 ,,
Clay	70 ,, 80 ,,
Peat	30 ,, 50 ,,

These figures show why 0·2 per cent. by weight of phosphoric acid is much more valuable in a sandy soil than in a clay; or, rather, how great is the difference in the amount of phosphoric acid which this small quantity represents when calculated over a large field. A clay loam soil, 6 inches deep, and covering an acre of ground, is estimated to weigh 1,000 tons. If this soil contains ·2 per cent. of phosphoric acid, there will be about 5,000 lbs. of phosphoric acid per acre. But should a soil of a peaty nature, weighing only 500 tons to the acre, contain ·2 per cent. of phosphoric acid, then there will be only 2,500 lbs. of phosphoric acid per acre. It will readily be understood that such a soil is far less fertile than the heavier soil, and this is really due to physical rather than to chemical causes, and a chemical analysis alone would not point out the fact.

A sandy soil is essentially a heavy soil, and a clay soil a light one. An error which this may lead to must here be guarded against. Farmers have given various names to the soil by which to indicate its peculiarities; they call it heavy or light, kind or unkind, hungry, sick, and similar terms, many of which might be more correctly applied to a human being than to the soil. These terms will be explained when the qualities to which they refer are mentioned. In the mouth of the farmer the terms 'light' and 'heavy,' as applied to the soil, are diametrically opposite to what they represent when speaking of their weight. The farmer calls a sandy soil light, because it lightly clings together, and is easily worked or ploughed; but a clay soil he terms heavy, because it is heavy walking and heavy ploughing.

Texture of soils.—This refers to the state of division of its particles. A clay soil is in such a minute state of division that it is impossible to see the separate particles. From the fineness of clay to the large lumps of stone found in sandy and gravelly soils there are a multitude of gradations. These are of interest not because of their direct effect, but because of their indirect effect upon the character and properties of the soil. Thus the moisture of a soil depends to a certain extent upon the state of division of its particles. What other properties depend upon it will be seen hereafter.

The soil in relation to moisture.—*Hygroscopic.*—If a salt cellar full of dry salt be left in the open air, the salt becomes damp. It has attracted moisture out of the air, and having this property is said to be a hygroscopic substance. Soil is to a certain extent a hygroscopic substance, and if perfectly dried and then left in the open air it will attract moisture.

Davy found that in one hour 1,000 parts of the substances given below absorbed from the air the following quantity of moisture :—

Coarse sand	8 parts per 1,000.
Fine sand	11 "
Ordinary sand	13 "
Fertile alluvial soil	16 "
Very fertile soil	18 "

Schübler also experimented upon this subject, and found that in twenty-four hours—

Ploughed land absorbed	23 parts of moisture.
Clay soil (medium)	28 "
Loam	35 "
Heavy clay	41 "
Garden mould	52 "

It is doubtful whether this hygroscopic power of the soil is due entirely to its state of division; in all probability it is partly due to the chemical composition of the soil. At the same time it will be noticed that, the finer the soil, the greater the quantity of water vapour thus absorbed.

Capillarity.—The soil has the power of absorbing not only water vapour, but water itself. When a tube with a very minute bore is placed in a glass of water, the water, contrary to the first law of liquids, rises in the tube above its level outside. These tubes being called capillary tubes, the action of water in them, or their action upon the water, has been termed capillary action. In a large tube the water will not rise, but if the tube be filled with soil, then the water immediately rises in it; being drawn up by the soil. The soil, therefore, is said to exert capillary action.

The extent of this action, and consequently the amount of water absorbed, depends upon the nature of the soil, differing apparently according to the size of its particles. The finer the particles, the greater the quantity of water absorbed. It has been shown that

100 lbs. of sand will absorb	25 lbs. of water.
100 lbs. of loam ,,	40 ,,
100 lbs. of clay loam ,,	50 ,,
100 lbs. of clay ,,	70 ,,

This explains why some soils always appear drier than others, and how after a shower of rain some soils become like a thick paste, others only comparatively damp. The fine clay absorbs nearly three times as much rain as the sandy soil, and retains it, while the sandy soil allows the greater part of the water either to run through it or off the top. Correspondingly, when dry weather comes the sandy soil is the first to give up its small amount of moisture to the air and to get dry, while the clay remains damp for a far longer period. Now the pure sand and pure clay are the two extremes. What the farmer requires is a medium soil. Hence in practice the farmer strives to loosen the adhesiveness and moisture-holding power of a clay soil, while, *vice versa*, he endeavours to increase the adhesiveness and moisture-holding power of a sandy soil.

Evaporation or transpiration.—Every soil partially yields up its water to the air. This is termed its power of evaporation, sometimes called transpiration. The lighter the soil, the easier will the water pass through it into the drains or underlying rocks, and the less will be the amount of water lost by evaporation. Thus evaporation depends partly upon the texture of the soil. The next, perhaps the most important, element in regulating evaporation is vegetation. A soil upon which there is any growth transpires far more than one which is bare. The water is first taken up by the plants and subsequently evaporated from their surfaces. Thus the plant transpires as well as the soil.

The following table shows results obtained by Mr. Greaves, and gives the average of fourteen years observations:—

Evaporation from Soils.

Rainfall in inches	Evaporation from water	From turfed soil		From bare sandy soil	
		Evaporation	Drainage	Evaporation	Drainage
25·72	20·66	18·14	7·58	4·24	21·48

This evaporation, however, depends upon many circumstances. Thus, between January and March it will be scarcely more on turfed soil than on bare soil. The same variation holds good of water. Thus, of the 20·66 inches evaporated in the year, the average summer evaporation is 15·89 inches, the winter 4·77. During the months of plant growth, the evaporation from the soil becomes so great as to allow scarcely any water to go through into the drains. This is in an average year; in a wet year the rain passes through into the drains to a far larger extent; at the same time the amount of evaporation rises also. A soil therefore is constantly gaining and losing water, and some water it retains.

Humidity.—It is of great practical importance that a soil should be able to retain a moderate quantity of water. Peat is most retentive of moisture, holding, like a sponge, as much as or even many times its own weight of it. The same is true of organic matter generally. Even when present in a soil in small quantities it exerts this property. Unfortunately the organic matter in a soil is usually valued simply in proportion to the amount of nitrogen it contains, its influence upon the physical properties of a soil being overlooked. The value of humus has been loudly decried, there may yet be much to learn about it however. There are certainly many facts not yet cxplained which may be due to this organic matter playing a part in the chemistry of soils not as yet understood.

The water-retaining power, or humidity, of a soil will be greatly influenced by the depth and nature of the subsoil. The greater the depth of a soil, the greater its power of retaining water. A shallow soil will allow the rain to pass through it rapidly, and, should great heat and drought ensue, it will dry up, and all vegetation upon it perish. A deep subsoil, on the other hand, will retain a store of moisture, which capillary attraction will bring to the surface soil as required. Hence the humidity of a soil and its other physical properties depend partly upon the subsoil. In times of excessive rain, if thc subsoil be sand or a limestone rock, both of which have large absorbing power for water, the soil is not likely to be flooded; but if the subsoil be clay the water will accumulate upon it, and, though it may not flood the surfacc soil, yet it will remain below exerting detrimental qualities, to be mentioned hereafter. The soil, then, in dry weather gives up its water to the air by evaporation, the surface soil becomes dry, and then the capillary power of the soil comes into play, and the water in the subsoil rises to the surface. If, on the other hand, rain falls, the water passes from the surface soil into the subsoil.

Thus in every soil there is a more or less continuous movement of water. This water is never pure, but contains some substances in solution. These substances consequently rise and fall in the soil with the rise and fall of the water, and probably this action of water in the soil plays an important part in supplying the roots of plants with food. There is ample proof that the water in the soil does hold salts in solution. In Peru the long dry summer brings an immense amount of soil-water up to the surface; it there evaporates, and leaves behind it the salt it held in solution, namely, saltpetre, or nitrate of potash, and large beds of this saltpetre are formed lying upon the surface soil. There are in other hot, dry climates beds of salts which have been similarly formed, consisting of nitrate of soda, whilst in the deserts of Utah incrustations of carbonate of soda are thus formed. The movement of this soil water, which generally contains carbonic acid, further plays its part in bringing the insoluble constituents of the soil into solution; for carbonic acid, as already pointed out, has a considerable effect upon the mineral matters of the soil.

There is one effect which is caused by the absence of water from a soil. Some soils upon drying shrink to a very considerable extent, regaining their size upon again becoming wet. Sand does not change in this way, but clay, as is well known, dries up into hard lumps, leaving the surface of the land full of cracks and large rents. If the clay be mixed with lime or sand then, instead of caking, it crumbles up, and as a result of the drying its texture is somewhat improved.

The effects of water on the physical condition and properties of the soil are thus seen to be very numerous.

Air in the soil.—When the small spaces between the particles of mineral or vegetable matter which constitute a soil are not filled with water they must be filled with something else. They are filled with air. This air has been analysed and is found to consist of the same gases as constitute the atmosphere, though they are not present in the same proportions. The atmosphere is a mixture of two gases, nitrogen and oxygen; it also contains carbonic acid gas. Whilst, however, the amount of carbonic acid gas in the atmosphere is very small, that in the soil is very large. Thus, in 100 parts of the atmosphere, there are of oxygen about 21 parts, nitrogen 79, and carbonic acid about ·4 parts. Whilst in 100 parts of the air from the interstices of the soil there are from 40 to 70 parts of nitrogen, 2 or 3 parts only of oxygen, and 30 to 60 parts of carbonic acid. The following table illustrates their composition:—

	Nitrogen	Oxygen	Carbonic acid.
Atmosphere	79	21	·4
Air of soil	40–70	2–3	30–60

That there should be so small a quantity of oxygen in the air of the soil is probably due to the fact that much of it has been utilised in oxidising organic matters and converting the carbon into carbonic acid. The presence of oxygen is nevertheless indispensable, as it is necessary in the early stages of the growth of all seeds.

These gases—oxygen, nitrogen, and carbonic acid—are all soluble in water, consequently, when rain passes through a soil, it absorbs some of these gases, and it is the carbonic acid and oxygen thus obtained which enables rain water to act upon lime and other substances in the soil, and to dissolve them. When this water again appears as a spring, or is fetched up from a well in the subsoil, it is found to be impregnated with those substances which it has dissolved in its downward course.

Relation of soil to heat.—The next property of the soil worthy of attention is the effect which heat has upon it. A certain amount of heat is required by every plant to make it grow. Hence plants live only between definite zones of temperature, or up to a given height on a hill or mountain side. But the earliest stage of a plant's growth is more affected by the temperature of the soil than that of the air. The temperature of the soil varies to a certain depth with that of the atmosphere. Soils, however, differ in the rapidity with which they are influenced by the temperature of the atmosphere above them, in other words they differ in the time they take to rise or fall in temperature. This is termed their relation to heat. When the sun shines directly upon the soil it will reach a temperature higher than the temperature of the atmosphere. Consequently the temperature of the soil is higher during the day than the temperature of the atmosphere; the atmosphere, in fact, receives much of its heat from the soil. When the sun's rays are no longer upon the soil it rapidly loses heat, and becomes lower in temperature than the atmosphere. Then it condenses upon its surface the moisture which that atmosphere contains. This causes the formation of dew, which produces such beneficial effects upon plants. Heat favours vegetation. Fruit trees, we know, are placed upon walls facing either south or south-east, so as to catch the direct rays of the sun. In the same way the heat of a soil greatly influences its fertility. This heat being derived from the sun, its effect will depend upon many circumstances.

Firstly, the slope or inclination of the land. It is easy to prove, by making a diagram of three soils, one sloping towards the sun, one perfectly horizontal, and one sloping away from the sun, that a greater number of the sun's rays will fall upon a piece of land the more it slopes upward, so as to meet the sun's rays at right angles. Hence, the greater the slope of the land from the sun, the less heat will it obtain. In England, ground facing south, and sloping upward at an angle of 25° to 30°, receives the greatest possible heat from the sun's rays.

The colour of the soil will next affect its temperature. If a white piece of paper and a black piece of paper be placed upon the snow in the sunlight, the snow under the black piece of paper becomes more rapidly melted than the snow under the white. This is an illustration of the fact that dark substances absorb the sun's heat rays. In the same way, the darker the colour of a soil, the more rapidly do the sun's rays warm it, while light-coloured soils, such as chalky soils, become warmed only slowly. The dark colour of soils is generally due, as previously mentioned, to the presence of decomposed organic matter. Hence soils rich in humus are generally warm soils. It is also probable that the oxidation of the humus, which is continually taking place, produces an appreciable quantity of heat. As a practical result of this warmth of soils, it is found that plants and vegetables sown in a dark soil ripen much earlier than those sown in a light-coloured soil.

In illustration of the preceding remarks, the following experiments may be quoted.

At noon of a July day, the temperature of the air being 90°, a thermometer, placed at a depth of about one inch beneath the following soils, gave these readings:—

Quartz sand	126° F.
Garden soil	115° F.
Yellow sandy clay	100° F.
Chalk soil	87° F.

These experiments were made upon dry soils, and the above remarks generally refer to soils in a dry state. The moment water is introduced there is a change of effect. The greater the amount of water in a soil, the slower it is to become warm. Consequently clay soils, which retain a large amount of water, are known as 'cold' soils, while sandy soils are designated 'warm' soils. The coldness of wet soils depends partly upon the inability of water to conduct heat, and partly upon the fact that a large amount of heat is expended in converting the water into vapour—that is to say, in drying the soil. Owing to this, the difference in temperature between a dry and a wet soil may amount to as much as from 10° to 15° Fahrenheit.

The following table, condensed from a large one, by Liebenberg, of Halle, illustrates the rapidity with which soils gain heat, and also the rapidity with which the heat penetrates into the soils, the readings being taken in each case at a depth of 2 cm. and 5 cm.: *i.e.* about ¾ inch and 2 inches.

Gain of heat by Soils.

	Original temp.	After ½ hour 2 cm.	5 cm.	After 1 hour 2 cm.	5 cm.	After 2 hours 2 cm.	5 cm.
	deg. C.	deg.	deg.	deg.	deg.	deg.	deg.
Water	21	26·0	26·0	29·5	29·5	31·0	31·0
Lime sand	21	29·0	27·5	32·0	31·5	36·5	37·0
Tertiary clay	21	30·0	27·5	33·0	30·0	36·3	35·0
Tertiary sand	21	30·0	28·0	33·5	32·5	37·5	36·5
Marl	21	31·0	28·5	34·5	32·5	39·0	37·5
Meadow loam	21	32·0	27·5	37·0	36·0	40·5	38·5
Rich loam	21	32·5	29·0	36·0	34·0	41·5	39·5
Basalt soil	21	33·0	28·5	35·0	33·0	42·0	38·0

The first noticeable result is the rapidity with which sand becomes warm throughout as compared with clay. Secondly, that as the soil becomes richer in organic matter it is capable of absorbing more heat. Thirdly, the slowness with which water warms, which explains, very strikingly, the coldness of damp soils.

The length of time during which the soil is capable of retaining heat once obtained is found to depend partly upon its physical texture, and partly upon chemical composition. It is greatest in sandy and gravelly soils—probably in those free from moisture.

Liebenberg has experimented also upon this subject, and some of his results are classified in the following table:—

Loss of Heat by Soils.

Nature of soil	Orig. temp.	After ½ hour	After 1 hour	After 2 hours
	deg.	deg.	deg.	deg.
Coarse sand	41·25	29·75	24·25	19·75
Fine sand	41·75	28·25	23·25	18·75
Marl	40·00	27·50	23·00	18·50
Loams	40·00	27·00	22·00	18·00
Clay	39·50	26·00	21·50	18·00

It is seen from the above table that clay soils rapidly become cold, and only slowly become warm; no wonder they are called 'cold' soils. The striking difference between the fine and coarse sand shows the value of working soils and so keeping them in a loose, open condition. Finally, it is evident that nothing so retards the warmth of a soil, and indirectly, therefore, its plant-producing power, as the presence in it of an excess of moisture.

Chemical properties of soils.—Absorption.—This is a property which soils possess, partly physical, but mainly chemical. It may be best explained by an illustration. Take some coloured water and pass it through several layers of soil, the soil will abstract some or all of the colouring matter from the water. As far back as the time of Bacon it was known that soil had the power of extracting certain substances out of a solution. From that time to the present day, experiments have occasionally been made which have resulted in the discovery of three properties peculiar to all soils:—

I. That of absorbing gases in considerable quantity.

II. That of extracting colouring and other matters out of solution.

III. That of decomposing a salt, such as chloride of ammonium, retaining the base—which in this instance is ammonia—and liberating the acid to combine with some other base.

Many theories have been put forward to try and account for these phenomena, more especially the third property of soils. One of them, propounded by Way, deserves some notice. The existence of silicates in the soil has already been explained, and also that there are silicates soluble in acid, as well as those insoluble. It is known that these silicates are capable of combining with other silicates to form what are termed double silicates. Thus a silicate of alumina will combine with a silicate of ammonia to form a double silicate, termed a silicate of alumina and ammonia. Way accounted for the decomposing action of soils upon salts by assuming that double silicates were always produced.

Recent researches point to other and far more complicated changes taking place in the soil. So far as we now know, the action is partly physical and partly chemical. The best illustration of the physical action is afforded by charcoal, which has the power not only of absorbing gases, but also many solid substances from solutions. Here there is no reason to suppose that it is a chemical action, but only a physical one. The charcoal filter is a familiar example of the practical application of this property of charcoal. The organic part of soils, or humus, appears to act like charcoal in taking salts out of solution by a physical property.

Of the substances which exert a chemical action upon the salts in solution clay stands first. Clay has an immense absorptive power. It consists of silicates of alumina and iron, and there are probably present, as well, hydrated oxides of iron and alumina. If any soluble salt containing phosphoric acid be washed into a soil, the phosphoric acid is immediately taken up by the hydrated oxide of iron out of solution. Phosphoric acid is the only acid of importance which the soil thus retains. All the other substances which it takes up are bases, such as potash, lime, &c. The following example will illustrate the effect produced. If a solution of ammonium chloride be put upon a soil, the ammonia will be withdrawn from the hydrochloric acid, and mainly retained. Its place will very probably be taken by soda, which substance will combine with the hydrochloric acid to form chloride of soda or common salt. This will be washed out of the soil instead of the ammonia. Of the various bases which soils are thus able to extract from solution, ammonia and potash are the most important. Though clay soils possess the greatest power of absorbing these substances, yet all other soils, including even sandy and calcareous soils, possess the same power in some degree. With regard to the absorption of ammonia, sandy soils have nearly as much power as some clay soils, but the whole of the ammonia in solution is not removed, though from a strong solution more ammonia is absorbed than from a weak.

The presence of lime in a soil is the most certain means of absorbing phosphoric acid. Clays and sandy soils also possess the power of retaining this acid. Experiments as to the effect which soils have upon potash salts prove that the potash is retained by the soil in large quantities, the acid being liberated. The following experiment made with a solution of nitrate of potash illustrates the method of experimenting employed by Voelcker in investigations of this description: 1,750 grains of a clay marl were shaken up in a bottle with 7,000 grains of a solution containing 25·55 grains of nitrate of potash. After standing three days the liquid was filtered off, and the potash and nitric acid determined in separate weighed quantities of the perfectly clear solution.

The following results were obtained :—

	Nitric acid	Potash
Before contact with soil solution contained	13·657	11·893
After ,, ,,	13·545	5·285
Retained by soil	·112 grs.	6·608 grs.

Thus the potash was retained by the soil, while the nitric acid was not. It was found that lime had combined with the nitric acid to take the place of the potash.

Nitric acid, then, is not retained by soils, but passes through them. It is the one, and only, substance of great value to the plant which the soil appears to have no power to retain. This fact is of immense importance, and will be frequently referred to hereafter. It also throws a special interest upon the property of soils, to be next considered.

Nitrification.—One of the most characteristic properties of soils is that of converting ammonia into nitric acid. It is termed nitrification. Ammonia consists of nitrogen combined with hydrogen. Nitrification causes the hydrogen to be taken away and its place supplied by oxygen. We may illustrate it thus :—

$$\begin{array}{ccc} \text{Ammonia} & & \text{Nitric acid} \\ \left.\begin{array}{l} \text{(Nitrogen) N}\left\{\begin{array}{l}\text{H Hydrogen}\\ \text{H ,,}\\ \text{H ,,}\end{array}\right. \\ \text{(Nitrogen) N}\left\{\begin{array}{l}\text{H ,,}\\ \text{H ,,}\\ \text{H ,,}\end{array}\right. \end{array}\right\} & \text{becomes} & N_2\left\{\begin{array}{l}\text{O Oxygen}\\ \text{O ,,}\\ \text{O ,,}\\ \text{O ,,}\\ \text{O ,,}\end{array}\right. \end{array}$$

It has long been known that some soils possessed the power of converting ammonia into nitric acid, which combined with the potash in the soil and formed saltpetre. Owing to the immense demand for saltpetre in the manufacture of gunpowder, the subject of nitrification has always received considerable study; but it is only recently that the real cause of the phenomenon has been discovered. It is now known that in every fertile soil there is a ferment, or organised structure, which is capable of converting ammonia into nitric acid. The effect which this ferment has upon soils under given conditions is of great importance, and, when better understood and more widely known, will probably induce considerable changes in the present systems of farming. Bearing in mind that the soil cannot retain nitric acid but allows it to pass into the drainage waters, it will be interesting to see the result of this ferment in inducing loss of nitric acid by the drains. Some results of experiments made by Messrs. Lawes and Gilbert, at Rothamstead, well show this loss. The drainage waters were collected from four plots, two of which had been left unmanured, and two of which had received manure between the first and second testing of the waters which drained through them. The following table gives the results of the analyses of these various drainage waters:—

Nitrogen, existing as Nitrates, per million of Drainage Water.

Drainage taken	Unmanured plots		Manured plots	
	A	B	C	D
February 16 .	3·3	4·2	3·5	5·2
April 7	2·3	3·6	39·0	45·4

The two plots unmanured give about the same amount on each date; but the two manured plots, which had received ammonia salts at the rate of 400 lbs. per acre on the 10th of March, have already had this ammonia converted into nitric acid, which is rapidly being washed out of the soil. It is easily understood, then, that the power of nitrification, possessed by all good soils under certain conditions, is one of very considerable importance.

Like all organisms, those which produce nitrification are subject to death, and possess, when alive, their peculiar relation to external circumstances. Firstly, with regard to temperature. These organisms lose their power of producing nitrification provided the soil or substance in which they are be brought to a temperature lower than 5° C.; but this power returns again upon a rise of temperature. Hence during the winter months nitrification will go on in the soil only slowly, and at times not at all. The activity of the organism commences at 12° C. and seems to increase as the temperature rises to 37°, when it is at its height; above 37° it begins to diminish, and stops at 55° altogether. At a temperature of 90° the animal dies. Apart from temperature, drying alone is sufficient to kill the organism. Neither temperature nor drying are ever sufficient in a soil to destroy it, though they will affect its influence to a considerable extent. The organism requires oxygen.

It is scarcely necessary to say that no sooner is the nitric acid formed than it at once combines with some base, such as lime, potash, or soda; if no such base be present, then nitrification is stopped. Of these bases lime is the most generally acted upon. Unfortunately the nitric acid becoming washed into the drains carries the lime with it. Thus one of the most valuable properties of a fertile soil is also a constant source of loss of two most valuable soil constituents.

CHAPTER V

CLASSIFICATION OF SOILS.

HAVING studied the chemical composition and physical properties of soils, a foundation has been laid for their classification. They may be divided into four natural classes according as they are sandy, calcareous, argillaceous, or peaty. But in every system of classification a place must be assigned to those intermediate varieties which do not distinctly belong to either one or the other of the chief classes. Many classifications have been proposed to accomplish this end, but they mostly fail to be of practical value, as they are too minute. For scientific purposes a minute classification is sometimes needful, but with the soil this is seldom, if ever, necessary. What is wanted by farmers is a simple system based upon science, but which shall be of practical use. The classification of soils is not like the classification of animals or plants, where a minute difference in structure needs to be taken into consideration because it may play an important part in modifying the function of the animal or plant. So far as our present knowledge enables one to judge, minute differences in the composition of soils do not influence the fertility of these soils. Thus two soils would be placed by some classifications in separate divisions, yet might be practically identical so far as their power of producing crops was concerned.

Taking, then, in the first place, the four natural divisions, we shall find that each of these can be subdivided.

Thus, for example, a sandy soil will be one in which sand preponderates to the exclusion of all other constituents. In most soils, silica, or sand, is the main ingredient numerically, but soils are not sandy properly so-called unless the other constituents are almost absent. If small quantities of lime be present in a sandy soil, such a soil will evidently be still sandy, though not exactly similar to a purely sandy soil. Hence it will constitute one of the many soils which, though mainly sandy, have yet some distinct peculiarity. In order to give such soils a place in the classification the class of sandy soils is divided. There are four divisions :—

I. Soils almost pure sand.

II. Sandy soils containing an appreciable quantity of lime.

III. Sandy soils containing an appreciable quantity of clay.

IV Sandy soils containing peat or vegetable matter.

It is advisable to divide the class of calcareous soils in a similar manner. Thus a calcareous soil will be either :—

I. Soil almost entirely lime.

II. Lime soil containing an appreciable quantity of sand.

III. Lime soil containing an appreciable quantity of clay (marl).

IV Calcareous soil containing peat or vegetable matter.

And the clay soils may also be subdivided into :—

I. Pure clay soil.
II. Clay soil containing sand.
III. Clay soil containing lime (marl).
IV. Clay soil containing peat or vegetable matter.

The four subdivisions of the peat class can be made, but are seldom used, as peat soil stands generally at an extreme distance from the other three kinds, and, being formed under peculiar circumstances, is not so mixed with mineral matter of various kinds as to require subdivision.

It will be noticed that two varieties of soil have been termed marl. Marl is a mixture of lime and clay. There are two kinds, the one a calcareous soil, termed a *calcareous marl*, because the lime will preponderate over the clay ; and the other, a clay soil, termed a *clay marl*, where the clay preponderates over the lime. The fourth division of each of the three classes will constitute what is termed a *loam*, a name applied to soils containing a fair proportion of organic matter. If the organic matter is very high, as in good, rich garden soils, it is termed a vegetable mould.

The following table illustrates this classification :—

Classification of Soils.

I.	SAND	LIME	CLAY	PEAT
II.	Calcareous sand.	Sandy lime.	Sandy clay.	
III.	Argillaceous sand.	Argillaceous lime. (calcareous marl)	Calcareous clay (clay marl)	
		Marls.	Marls.	
IV.	Peat and sand. (sandy loam)	Peat and lime. (calcareous loam)	Peat and clay. (argillaceous loam)	Vegetable moulds.
	Loams.	Loams.	Loams.	

This is a very simple classification, yet it is probably sufficient for all practical purposes, being minute enough to separate soils which would require different methods of cultivation, or necessitate a limitation of crops, or influence the general farm management.

Besides this classification of soils based on chemical considerations, there is another classification in vogue among farmers based on geological formation.

Thus we frequently hear an 'old red sandstone soil' or 'an oolite soil' spoken of. There is a good deal of practical value attached to such a classification, because experience has shown that certain crops will flourish upon soils of a definite geological formation. Probably chemical analysis would show such soils to be very similar in chemical composition, but such information is not yet forthcoming.

From the preceding remarks on the causes of the various physical properties in soils, it will now be easy to understand the characteristic properties of each class.

Sandy soils are dry, porous, light, warm, and subject to drought; they are seldom flooded, for water passes rapidly through them, hence soluble constituents are rapidly washed out. Moreover, they possess the power of chemically holding these substances in themselves only to a slight extent.

Calcareous soils are dry, light to work, cold, porous, and subject to drought; they are seldom flooded, seldom deep; water passes rapidly through them, but has not quite so much power in washing out their constituents as from sandy soils.

Clay soils are wet and cold, difficult to work, and not porous; water flows over the surface and only with difficulty soaks through them. Owing to their powerful retaining properties the water does not wash out the fertilising constituents.

Peat soils are, when cultivated, light, warm, and porous, but hold a large quantity of water and are liable to become cold; they are easy to work, and not subject to drought.

Soils are either fertile or barren (infertile). The fertile soil may be best described by negative properties, or the absence of any of those elements which go to make a barren soil. The more closely a soil approaches a happy mixture of the four elements, sand, clay, lime, and vegetable matter, the more nearly will it approach to a perfect soil, both physically and chemically. The nearer it approaches to the composition of one single element to the exclusion of others, the nearer will it approach to barrenness, or infertility. It would be useless to describe the thousand and one grades of composition which lie between these extremes, and equally useless to try and classify them. As will be seen when the causes of infertility are studied, chemical analysis can alone discover whether a soil be barren or fertile; its place in a classification will not help in the least.

For this reason no analyses have been given, as is so often done, which are supposed to represent the composition of the soils forming each division of the classification. Long experience has convinced me that such analyses are useless and misrepresentative.

Infertile soils.—The unproductiveness of a soil may depend upon its physical condition, as would be the case with an undrained clay, subject to excessive moisture; or it may be due to its chemical composition; and this may be owing either to its containing some injurious substance, or to its being deficient in some necessary substance. Whatever may be the cause, it is capable, if known, of being surmounted; it follows that the knowledge of the various causes of unproductiveness is of considerable value to the agriculturist.

Physical causes of infertility.—The chief physical causes of the infertility of soils, those which induce excessive moisture, have been already described. Soils resting upon an impervious subsoil are mostly unproductive, because they are not capable of being brought into that physical condition which is a necessary requisite of a fertile soil. There are various kinds of impervious subsoils, each capable of treatment that will remove any ill effects it may have produced. A tenacious clay may underlie a naturally good surface soil. In such an instance drainage will carry off the superabundant water and remedy the evil.

Some soils are liable to a very peculiar formation in the subsoil, which soon renders them totally unfit for profitable cultivation. It is found that, at a depth varying from 8 or 9 inches to a foot or more, there has been formed a layer of substance as hard as stone, quite impervious to water and to the roots of plants, and entirely cutting off the top-soil from communication with the subsoil. This layer is called a *pan*. Before the soil can be properly worked the pan must be broken up, an operation not by any means easily performed, but if once performed thoroughly the pan never reforms. These pans are caused in various ways, and according to their formation have received various names.

The Moor pan is the most important, and most frequently found, more especially in peat soils, such as exist in many parts of Ireland. It is caused by iron. Salts of iron and iron oxides exist in peaty soils in considerable quantity; they are partly soluble and are washed down into the subsoil. At a certain depth, generally about a foot, they become deposited, or crystallise out of solution; gradually accumulating, they at length form a hard semi-crystalline rock-like layer of several inches in thickness, and thus constitute the iron or moor pan. Calcareous pans are similarly formed, consisting of lime salts; and vegetable pans, consisting of organic or peaty matters, have been met with. The Indurated pan is formed if a field be constantly ploughed at the same depth. The treading of the horses, and the weight of the plough coming over and over again on the same earth, gradually consolidate the subsoil into a slight pan, termed an indurated pan.

Chemical causes of infertility.—Acidity.—Substances are injurious to vegetation which give to the land an acid reaction. It is easy to test whether a soil be acid or not, by mixing some with water, and allowing a piece of blue litmus-paper to stand in it; if the soil be acid the paper turns red.

If a soil contains a large quantity of organic matter, this upon decomposing is converted by oxidation, as already mentioned, into acid substances, humic acids, and, if the soil does not contain a sufficient quantity of lime to neutralise these acids, they will remain in a free state, and give to the soil an acidity which prevents vegetation. The cure for this acidity is the application of caustic lime, which neutralises the acids, and helps their further decomposition. This is why lime is often said to sweeten land. Another cause of an acid reaction is sulphate of iron. This compound is the result of the oxidation of sulphide of iron or iron pyrites; consequently, along with the sulphate of iron, the soil generally contains some sulphide still unoxidised. This sulphide is easily distinguished when the soil is treated with acid, for it gives off sulphuretted hydrogen gas, the disagreeable and well-known smell of which at once indicates its presence. Soils which contain the sulphate or sulphide of iron need to be well worked, so as to bring the whole of the soil into intimate contact with the air; it is also well to add lime, which will destroy the sulphate; by these means the compounds become further oxidised, and rendered harmless, being converted into ferric oxide. This change is generally accompanied by a change in colour, from a bluish, or greenish, or yellow colour to a red colour. It is probable that, like humic acid, the sulphide and the sulphate of iron are not merely injurious compounds themselves, but indicators of the fact that the soil is not properly aërated, and does not therefore obtain a sufficient supply of oxygen, which oxygen has been proved to be essential to plant life.

Salt.—Common salt, if present in a soil in any quantity, will cause it to be unproductive. The same effect is produced by all saline compounds soluble in water, which if present in the soil in very large quantities prove injurious to vegetation. It is not possible to put an exact limit upon the quantity of these saline compounds which may be in a soil, so as to state whether a given soil will be or will not be productive. A large number of analyses showing the quantity and nature of the substances soluble in water prove that in fertile soils these seldom reach above ·1 to ·2 per cent.; they exceed this in peat or salt soils, both of which are comparatively unfertile. Knop has shown that a solution containing one part of mineral matter in 1,000 parts of water is of the strength from which plants are best able to draw food and grow. This is also found to be the average strength of a water solution of good arable soil. The quantity of common salt present in some unfertile soils will alone yield this amount to a solution, and is sufficient to cause their infertility.

Constituents absent.—Soils may be unproductive if they do not contain all the constituents necessary for plant life. Of these the three most frequently absent are lime, potash, or phosphoric acid. No soil deficient in either one of these substances can prove fertile. A deficiency of these ingredients is found principally in sandy soils, such soils being deficient sometimes in one of these substances, sometimes in two, or even in all. Clay soils are sometimes deficient in lime, sometimes in phosphoric acid; but as a rule they contain sufficient potash. This is easily understood when the composition of the rocks from which they are mostly formed is remembered. Sandy soils are most frequently deficient in phosphoric acid. The following analyses will illustrate the composition of some unproductive soils:—

Unproductive Sandy Soils, deficient in

	Lime	Potash	Phosphoric acid
Moisture and organic matter	3·62	6·92	3·02
Iron and alumina	7·50	6·43	4·34
Phosphoric acid	·13	·11	·07
Sulphuric acid	—	—	·06
Lime	·43	·65	·21
Magnesia	·49	·39	·41
Potash and soda	·48	·33	·26
Silica	87·35	85·17	91·63
	100·00	100·00	100·00

Unproductive Clay Soils, deficient in

	Lime	Potash	Phosphoric acid
Moisture	7·03	4·01	12·37
Organic matter	12·58	8·51	8·07
Iron and alumina	11·10	11·24	14·45
Phosphoric acid	·48	·06	·01
Sulphuric acid	·11	·19	·10
Lime	·13	none	·04
Magnesia	·33	·46	·37
Potash and soda	·52	·45	1·21
Silica	67·72	75·08	63·38
	100·00	100·00	100·00

If, then, on the one hand some soils are unproductive from an excess of injurious substances, others, and by far the greater number, are unproductive from a deficiency of necessary substances. It is evident that the remedy lies in supplying the substance wanted, and it is partly to supply such deficiency that manures are used. It will be seen, however, from the preceding typical analyses that soils are seldom deficient in one constituent only, that more frequently two are absent, and sometimes three. It will then become necessary to apply all three substances in due proportion ; hence the value of artificial manures which will soon have to bc studied, and that there is a deal of scope for ability in their profitable application will be evident.

Soils sometimes appear unproductive from having an excess of one constituent, such as lime or clay. It is difficult to say that this is the real cause of their unproductiveness ; such soils are frequently deficient in some essential of a productive soil, and they have, as will be remembered, exceptional physical properties.

CHAPTER VI.

THE IMPROVEMENT OF SOILS.

THE study of the chemical composition of soils, and subsequently of their physical properties, has clearly pointed out that soils are not alike in their properties, and that they are not all possessed of similar advantageous qualities. It has been seen that some soils are absolutely barren, while others which are fertile are not all endowed with similar degrees of fertility, nor with properties wholly beneficial to plant life. The constant desire of the agriculturist must ever be then to make unfertile soils fertile, and to get rid of any undesirable properties in fertile soils. In either case the result will be the improvement of the soil. Of the many objects of agricultural practice none is more important than the improvement of the land. The notion put forth by some agriculturists, and supported by so great an authority as Sir J. B. Lawes, that 'profitable agriculture involves a slow but continuous exhaustion (of the fertility) of the soil,' is erroneous and dangerous. The true object of agriculture is to improve the fertility of the soil whilst gaining from it normal crops. If it were not so, then every field that is cultivated or ever has been cultivated would during such time have suffered loss, and as a consequence there would come a time when it would pay better to stop cultivating such lands, and to open up fresh ground. Experience has taught men that this is not so, for the most fertile soils in the land are those which have received for many years careful cultivation. Moreover, many soils before they can be well and profitably cultivated have to be improved by cultivation.

The methods of improving the soil may be classified under two heads: firstly, those which affect its physical properties, and secondly, those which affect its chemical composition.

The improvement of the physical properties of soils.

It has been seen in treating of these physical properties that nothing so affects the soil as water; that while a sufficiency of water is a necessity, an excess of water is most detrimental. The first method of improving soils aims, then, at controlling this influence of water upon the soil, and is termed drainage.

Arterial drainage.—We all know that water, owing to the property of finding its own level, has formed in rivers and streams a natural means of draining the island of the water that falls upon it. The brooks thus formed, however, leave many large tracts of country totally at the mercy of the rain, and in time of heavy rains these lands are flooded. Now it is essential, before any land can be drained for agricultural purposes, that the country itself in which this land is situated should be drained. The draining of a large tract of country is termed arterial drainage, and the expense is such that it can only be done by large companies, or more properly by the Government of the country

It is the want of this arterial drainage which is so much against the Irish landowner or cultivator, whilst in England the system of arterial drainage is good, though probably not all that may be desired. With those who purpose emigrating, the question of arterial drainage should be well considered; so long as one's land is near a river, or has a stream running through it, there is a possibility of draining the land, but the further one recedes from the river the less the possibility, and the greater the expense should it become necessary, as it probably would for arable farming.

Land drainage.—Presuming then that a country is well furnished with an arterial drainage system, what soils would require drainage?

Firstly, this will depend partly on the nature of the soil, partly on the nature of the subsoil. Where the soil is light, or rests upon a porous subsoil or material, no drainage may be required. Where there is clay land, whether on the surface or forming the subsoil, drainage will invariably improve its condition, whilst in many such cases drainage becomes an absolute necessity. Peat lands also need drainage.

Secondly, it depends upon the climatic conditions of a locality. Thus, in places where the rainfall is excessive soils must be drained, whilst similar soils in a locality with a small rainfall would not require draining.

Thirdly, the position of the land will materially affect the necessity of drainage. Thus, much of the rain which falls upon steep sloping ground runs off the surface, whereas on flat, low-lying ground this water would lie upon the surface unless the land were drained.

Lastly, where underground springs occur it will be necessary to drain the land, so as in some measure to direct their course.

Thus it will be seen that all soils do not require draining, though heavy clays invariably do; and some slight idea will be gained of the general nature and position of land most benefited by drainage.

It may be well here to state that, while draining is beneficial to land in carrying off superfluous water, it has not been found injurious in time of drought. Drained soils generally retain or are able to obtain, by their capillary attraction and by absorption, a quantity of water sufficient for the growth of the plant during a dry period.

History of drainage.—When the practice of drainage first commenced it would be difficult to say. It first received practical form at the hands of Mr. Elkington in 1763. His system aimed at getting rid of the water of springs. It consisted in digging a trench to carry the water off, and then digging a shaft down into the underneath strata. The water now rose in the shaft and flowed away by the trench; thus the water-level of the surrounding land sank to that of the level of the water in the trench. 'Whenever an alternation of permeable and impervious beds occur, giving rise to springs, then Elkington's system may be carried out; but in homogeneous clay soils, or in any soil of uniform character, wet from surface-water or rainfall,' another course must be adopted. Mr. William Smith, in 1836, made drains by cutting out the soil to a depth of 22 inches, partly filling the trenches with stones, and then filling up with the earth again.

He also it was who first arranged the drains parallel to one another. Subsequently, in 1843, the stones were supplanted by drain pipes, and thus the present method of draining arose. Certain slight modifications have since been introduced, making the practical carrying out at the present day somewhat as follows.

The first rule is that the drains must not be too long; therefore it is considered best to drain each field of a farm separately. This naturally depends upon the size of the fields, and presumes that they are of moderate size. Small fields are bad for draining and in many other respects, as will be seen hereafter.

The direction of the drains will always be such as to lead the water to the lowest part of the field. Should the field be tolerably level, then the drains must be sloped about 1 foot in 500 feet, so that they will lie at different depths from the surface soil; if the land itself slope, then the drains will be laid at a uniform depth from the surface of the soil, and slope with the land. The drains will consist of one *main* drain and several small *lateral* drains. The main drain will occupy the lowest part of the field, whether it be along one side or down the middle. The small drains will enter the main drain either at right angles or at a smaller angle, and lie parallel to one another. This is easy enough in a perfectly or tolerably level field, but in one containing large hollows it is impracticable. To surmount this difficulty, each hollow must be furnished with a *submain* drain, with its corresponding small side drains.

The main object is to have the drains constructed in such a manner and of such material that they will not get blocked up. It appears to be universally granted that earthenware pipes are the best to attain this end. Such pipes are termed drain pipe tiles. There are three different shaped pipe tiles: The common cylindrical pipe tile, the horse-shoe pipe tile with a flat-resting edge, and the egg-shaped pipe tile. In practice the cylindrical pipe tiles, being the cheapest, are most frequently used. The egg-shaped pipe tile is a little dearer, but is the best.

These egg-shaped tiles are—for main drains $3\frac{1}{2}$ inches in width, and 5 inches high in the bore; for side drains $1\frac{3}{4}$ inch wide, $2\frac{1}{2}$ inches high, and 15 inches in length. In draining a field the pipe tiles are put nearly close together, their ends being only about $\frac{1}{8}$ of an inch apart. The openings so left, however, are all that is necessary to enable the water to enter the pipes, and the pipes being unglazed are themselves slightly porous. Considering there are two such openings for every yard of piping, we can understand the immense number spread over a whole field. In fact the area of these openings amounts to nearly 200 square inches for every 100 yards of drain pipes. The opening of the main drain, where it enters the brook or stream which finally carries off the water, is termed its mouth. This should invariably be protected by a grating, and kept free from all dirt. Drains must be laid some distance from trees and hedges, lest the roots penetrate them, and block them up as well as destroy them.

The object of drainage is to keep the level of the stagnant water in a soil down to the level of the drains. The soil above this level will be damp, owing to its capillary action. Now, should rain fall on the land, it will gradually soak down into the soil, and tend to raise the level of the stagnant water. But the moment this stagnant water reaches the bottom of the drain it will begin to flow away. Hence drainage waters enter the drains not by percolation from above, but by raising the level of the water below the drains; in other words, the water rises into the drains from below.

We are now in a position to enter upon the discussion of several important and moot questions with regard to the method of draining land.

Depth of drains.—To what depth ought drains to be placed is a question over which there has been much discussion. Now, as an ordinary plough ploughs to a depth of 7 or 8 inches, and a subsoil plough ploughs another 7 or 8 inches lower, there must be sufficient depth of soil between the subsoil furrow and the top of the drain to preserve the latter from injury. Taking this distance to be 6 inches at least, and considering that a main drain tile stands 6 inches high, it is evidently impossible to have a drain, in a highly cultivated arable field, at a less distance than 28 inches from the surface. Where the land is steam ploughed, a greater depth of soil is frequently moved than that above mentioned, whilst the weight of the machinery is greater; the drains must therefore of necessity be much lower, say 36 inches. These, however, are minimum depths. It is generally considered that the best depth at which to lay drains in arable land is 4 feet. On light lands drains are sometimes placed at depths greater than this, while on heavy clay soils the drains will be a little higher, being about 3 feet or so deep. The depth varies with the texture of the soil; the more easily water passes through the soil, the deeper may the drains be. The distance apart of the side drains also varies with the texture of the soil; the heavier the soil, the nearer must they be together. In very heavy clay land they should lie about 20 feet apart; in moderately stiff clay about 30 feet is ample; and in light arable land 40 feet apart will not be too far; in some very porous light soils they are laid even as much as 60 feet apart. Thus it will be seen that the heavier the land, the nearer the drains both to the surface and to one another; the lighter the land, the further apart they are and the deeper. Such is the practice regarding the draining of arable land.

The drainage of grass land is generally surface drainage only, and consists of a series of shallow trenches, dug out by the spade or made by a plough. This surface drainage greatly enhances the value of pasture land; it improves the herbage and makes the surface of the ground much drier, a point of considerable importance to sheep, as they need a tolerably dry footing. It is sometimes the practice to drain sheep lands with covered drains. If pipe tiles are used, these may be laid one foot deep. Sometimes drains are made somewhat similar to those shallow trenches already mentioned, but having the top covered over, and so leaving in the bottom an open channel. These channels, however, are liable to become blocked up.

The advantages of drainage.—Owing to the quantity of rain which falls on most soils, it can well be understood that soils are for the greater part of the year wet. If the soil be drained, this water is in constant motion passing through the soil; if not drained, the water is stationary, *i.e.* stagnant. The advantages of drainage are not so much positive as negative; in other words, they are due to the absence of the injurious effects produced by stagnant water, rather than to any beneficial result due to the passing of the water through the soil. If the soil be drained the rain will flow through the soil, hence more water passes through a drained than through an undrained soil. This, indeed, is one object of drainage, not so much to get the water out of the land as to get it into the land. By this means many of the fertilising constituents of rain water become taken up by the soil. The rain which falls upon a soil is often much warmer than the soil, consequently in passing through into the drains it gives up its heat to the land. More especially is this the case in spring, that period of the year when warmth is most essential to the plant. Moreover, when water passes through a soil it draws air after it, the oxidising and beneficial effects of which upon the organic matters of a soil have already been explained. It soon becomes apparent on a newly drained soil; the soil rapidly improves, and substances injurious to vegetation are prevented from forming. By thus bringing air and water alternately into the soil, its physical conditions are improved, the land becomes more friable, the roots of plants penetrate the soil with ease, and the cultivation of the soil becomes much lighter. Finally, the injurious effects of stagnant water are prevented.

Effect of stagnant water on the soil.—If some water is placed in a dish and left in the open air it gradually evaporates. In passing from the state of liquid to that of vapour it absorbs heat, and so eager is the vapour for heat, that it robs the water of all it possibly can, and thus considerably lowers its temperature. The stagnant water in a soil acts in an exactly similar manner to water in a basin. It evaporates from the surface, leaving the remainder cold. Hence stagnant water lowers the temperature of a soil. Evaporation does not take place to such an extent with drained lands, simply because there is less moisture in the surface, hence drained land is warmer than undrained. The effect of water in lowering the temperature of soils has been experimentally demonstrated. Thermometers were sunk into a bog at various depths, one part of which was drained, the other part not drained. The temperatures obtained at the various depths were as follows: For the undrained bog, 46° F. at all depths; for the drained bog, 60° F. at 7 inches deep, and 48° F. at 31 inches deep.

Two other properties of water tend to lower the temperature of undrained land. Firstly, water is a very slow conductor of heat downwards, because the hot water always keeps at the top; consequently the heat of the sun's rays sinks very slowly into a soil full of water. Secondly, water cools very rapidly, and soon gives up any heat it has received from the sun; so that soils saturated with moisture not only warm slowly, but rapidly lose that warmth the moment they lose the sun's rays. The table on p. 68 proved how slowly some soils gave up their heat as compared with water. Hence draining land not only increases its temperature, but also enables the land to retain that increased temperature.

These are more or less theoretical or scientific considerations in support of drainage. Farmers find in practice the advantages of drainage to be equal to those that science would anticipate. Crops ripen more rapidly, they yield more abundantly, and are less liable to disease. Moreover, a greater variety of substances can be grown. The live stock is healthier upon drained land than upon undrained land. Finally, what may be termed the climate of the farm is materially improved.

Having seen the effect of drainage on the water of the soil, the questions arise—How much rain passes away by the drains? and how much is retained by the land, or given off by transpiration? Some experiments made by Messrs. Lawes and Gilbert at Rothamstead will serve to partly answer these questions. The experiments extended over some years, and the results are given in the following table:

Quantity of Drainage Waters.

Years	Rainfall	Drainage through drains	
1875	inches	40 inches deep.	60 inches deep.
to	34·19	18·54 inches	16·90 inches
		Percentage of rainfall.	
1880		54·2	49·4

Thus, under the conditions which existed in these experiments, more than half the rain which fell in the year passed into the drains. The remainder of the rainfall was transpired by the plant or evaporated from the soil. The amount passing away through the drains will, of course, vary with the nature of the soil. It will be noticed that the drains 40 inches deep carried away more water than those 60 inches deep.

The questions arise—What does rain water bring to the land? and what does drainage water take away? It will be remembered that the water passing off by evaporation, or transpiration, is absolutely pure, it takes away nothing.

Rain water.—It has long been known that rain water is not quite pure, but brings down to the soil certain constituents of the air in solution, whilst it also mechanically carries down floating particles of solid matter. Thus it is that the atmosphere after a shower is so fresh and invigorating.

The following table illustrates the composition of rain water:—

Composition of Rain Water (Lawes and Gilbert) in parts per million.

	Total solid matter	Nitrogen as			Total Nitrogen	Chlorine
		Organic matter	Ammonia	Nitrates and Nitrites		
Collected 3 P.M.	40·8	·18	1·07	·18	1·43	1·0
„ 4·30 P.M.	29·4	·19	·37	·13	·69	·8
Mean of 69 samples	33·1	·19	·37	·14	·70	3·1
		Dew and Hoar Frost				
Mean of 7 samples	48·7	·76	1·63	·40	2·79	5·3

It will be seen that a comparatively large quantity of matter is brought down to the soil by rain, but the constituent most valuable is nitrogen. The quantity of nitrogen thus acquired by the soil varies greatly, and the above analyses probably represent far less than the average quantity so acquired. The quantity, however, depends on certain conditions. In rain which falls over towns, from 3 to 5 parts of ammonia are found in 1 million parts of rain water, whilst in rain which falls in the country only 0·7 to 1 part per million is generally found. It follows that every acre in the country receives from the rain about 10 lbs. of nitrogen per annum either as ammonia or nitric acid.

The other constituents of rain are of slight importance. The quantity of chlorine is due to the presence of common salt, and becomes greater the nearer the sea is approached.

Dew and hoar-frost.—In nearly every month of the year there takes place during the night a deposition of moisture upon plant growth, and upon the soil. This is known as dew when in the liquid state, but when it becomes frozen is known as hoar-frost. The analyses of dew and hoar-frost show that these also contain large quantities of nitrogen, but the quantity of water thus brought to the soil, and hence the quantity of nitrogen, has, so far as I know, never been accurately determined.

Drainage waters.—Rain in passing through the soil may either run rapidly down the larger channels in the soil, or permeate the mass slowly until, the soil becoming saturated, the rain flows away by the drains. The rain may give up its constituents to the soil, or take up constituents from the soil.

The composition of drainage waters will at once explain which of these and what changes take place. Drainage waters have been thoroughly investigated by Professor Way, by Dr. Voelcker, and by Professor Frankland. Dr. Frankland analysed the waters flowing from the drains at Rothamstead, previously mentioned, and the mean of his analyses gives the following results:—

Composition of Drainage Waters in parts per million.

Drains	Total solids	Nitrogen as			Total Nitrogen	Chlorine
		Organic matter	Ammonia	Nitrates and Nitrites		
40 inches deep	289·0	·49	·02	18·46	18·97	17·1
60 inches deep	314·7	·55	·08	20·40	21·03	15·4

These analyses have been amply verified by many others made in different years. The results have been, practically speaking, the same. A large quantity of nitrogen therefore passes annually into the drains and is lost. It will be noticed that this nitrogen is mainly present as nitric acid. Calculating the quantity of nitrogen thus lost from the drains in lbs. per acre, the following results are obtained:—

Annual Loss of Nitrogen in lbs. per acre.

In years	40 inch drains	60 inch drains
	lbs.	lbs.
1878	36·92	44·53
1879	34·42	48·27
1880	43·31	46·26

Thus it will be seen that a soil which gains approximately 10 lbs. of nitrogen per acre from the rain as ammonia, loses four times as much, or 40 lbs. of nitrogen per acre, through the drains as nitric acid.

It must not be forgotten that the quantity of nitrogen brought to the land by dew and hoar-frost has not been taken into account for reasons previously pointed out.

This discovery, one of the most important of modern science as applied to agriculture, was made by Dr. Voelcker, though Dr. Frankland's confirmatory analyses have served me best to illustrate the subject.

From these results it is evident that the object of the farmer should be, whilst reaping the benefits of drainage, to guard against excessive loss of drainage water. This is best attained by allowing the land to lie as short a time as possible without a crop, for it has been previously shown that where a crop is on the land the amount of water flowing through the drains is much less than where there is no crop; consequently there is far less waste of nitrogen from soils bearing crops.

The analyses of drainage waters illustrate several important points in connection with the chemical action of soils, more especially their action upon manures.

It has been shown above that one of the results of draining land is to cause a large amount of matter valuable to the plant to be washed out of the soil. It may be asked—Are not other substances simultaneously washed away, and if manures, soluble in water, are applied to the land, will not they also be washed away? These two important questions are conclusively answered by the complete analyses of drainage water made by Dr. Voelcker some years ago.

The following table gives the results of some of these analyses :—

Drainage Waters from Field where Wheat is grown every year.

Grains per gallon of	Unmanured	Superphosphate, potash, soda, and magnesia				400 lbs. ammonia salts, =82 lbs. nitrogen		
		Without ammonia salts	400 lbs. Am. salts, 82 lbs. N. (April)	400 lbs. Am. salts, 82 lbs. N. (January)	550 lbs. nitrate of soda, 82 lbs. N.	Without mineral manures	Superphosphate of lime	Superphosphate and potash
Organic matter	1·50	1·45	2·60	2·60	4·01	3·10	2·20	3·45
Oxide of iron .	·25	·30	·45	·25	·35	·25	·25	·15
Phosphoric acid	·04	·10	·06	—	—	·06	·05	·05
Lime .	5·96	6·66	8·01	16·49	10·75	7·78	8·20	7·02
Magnesia . .	·47	·46	·56	·54	·69	·52	·46	1·11
Potash	·07	·20	·18	·13	·43	·06	·10	·13
Soda	·67	·78	·49	1·06	6·57	·41	·28	·30
Chlorine .	·58	·65	1·16	1·97	1·02	1·24	1·24	1·46
Sulphuric acid .	·79	2·62	3·33	9·21	1·67	2·71	2·69	3·70
Nitric acid .	·23	·37	1·21	7·59	15·74	2·74	2·06	1·52
Carbonic acid .	3·24	3·91	2·80	·20	5·77	3·18	2·57	3·66
Soluble silica .	·35	1·35	2·80	4·51	·85	·60	·80	5·20
Total solids	14·15	18·85	23·65	44·55	47·85	22·65	20·90	27·75

These figures enable the following answers to be given to the two questions just asked.

Firstly, as to the substances washed out of the soil. It is evident that nitric acid is the most important substance lost through drainage. As the quantity of lime invariably increases with the quantity of nitric acid, these substances are probably washed away in the form of nitrate of lime. The loss of lime which land thus sustains is considerable, and when it takes place from soils possessing naturally but a small quantity of lime, the loss becomes so important that it has to be replenished by fresh lime being added to the soil. As no trace of ammonia can be discovered in drainage waters, it is evident that before nitrogen escapes it must be converted into nitric acid by the process of nitrification previously described.

From this can be estimated the effect of drainage upon manures containing nitrogen. It is evident that these manures are, to a large extent, washed slowly into the drains. Nitrate of soda will thus be lost far more rapidly than ammonia salts. This is illustrated in the table of analyses. The fifth column shows that the nitrate of soda applied shortly before is already passing down into the drains; the third column shows that the ammonia salts remain in the land, and do not get exhausted until in the winter the drains again begin to flow, when, as shown by the fourth column, they appear in the drainage water as nitric acid.

With regard to the other substances washed out by the rain, those of most importance to the plant are conspicuous by their absence. Thus, phosphoric acid is neither lost from unmanured soil, nor is it washed out of the soil even when placed upon the land in a soluble state as superphosphate of lime. This is shown by the first five columns, though more especially by the seventh.

Potash, another substance of value to the plant, and one which forms salts most soluble in water, is, strange to say, retained by the soil, and even when added as manure, is not washed into the drains, as is proved by column eight. Soda, however, is rapidly washed away, not only from unmanured soil, but especially from manured soil, as is seen in column five. This, however, is of no great consequence, as soda itself is of little, if any, value to vegetable growth.

Of the other substances washed into the drains, the most important are sulphuric acid, soluble silica, and chlorine.

Thus it will be again seen that, while the soil retains with avidity basic substances, it allows acid substances to be washed out of it with ease.

Some soils in spite of draining are yet not in a fit state for cultivation, they need other means of improvement as well. Thus heavy clay soils not amenable to simpler means, and clay soils which have become rank with herbage, require to be *pared* and *burnt.* This operation is also performed on some very thin soils.

Paring and burning.—These operations and the effects produced by them are as follows:—

A thin portion of the surface of the ground, about 3 inches deep, is first pared off, then set up in heaps, and so soon as dry burnt at a low temperature. The ashes so formed are subsequently spread over the ground. The paring of the surface is performed either with a spade, or, what is better, by a plough specially shaped for the purpose, which cuts a slice about 14 inches wide, and sets it upon its edge on the pared ground ready to be dried by the sun and atmosphere. This operation must be done at a dry period of the year, consequently the early period from February to April is found best; this will also enable the land to be got ready for a turnip crop, which crop generally follows paring and burning. All land is not benefited by paring and burning, and even land which is benefited will not bear a repetition of the operation frequently. Lands in the fen country of a peaty character, and thin soils (calcareous clays) on the Cotswold Hills, have hitherto yielded the best results from paring and burning. It is often advisable in other parts of the country, on clay soils which, after having been laid down to pasture for some years, have become matted with weeds or old herbage roots, especially sainfoin roots. Generally speaking, it is most suitable for soils impervious to moisture and air, in which the organic remains of plants lie unoxidised.

The effects of paring and burning are twofold: its action upon the organic matter of the soil, and its action upon the inorganic matter. It is evident that the organic matter of the soil, which in a previous chapter has been shown to confer valuable physical properties on the soil, will upon burning be destroyed. This has caused many to look upon burning as perfect folly, and, indeed, its use is rapidly declining. One of the principal properties of the organic matter in the soil is its power of absorbing moisture and plant food, such as ammonia. Clay possesses this same power, and it is found that soils upon which paring and burning are practised with good results invariably contain a fair proportion of clay. This is probably the reason why such soils do not suffer, even though they lose their organic matter. Upon sandy or light soils paring and burning would be a mistake. Though the organic matter is destroyed by burning, fresh organic matter is soon given to the soil, for a turnip crop immediately follows which is eaten by sheep on the land ; their droppings will thus return to the soil sufficient organic matter to supply the requirements of the following crop of barley or wheat ; a small quantity of organic matter, in the shape of roots and leaves, will also remain in the soil.

Upon burning organic matter, all the mineral constituents which it contains are left behind ; and, as land which is burnt generally contains large quantities of organic matter, so the ash obtained from this organic matter is not inconsiderable. The organic matter will consist largely of weeds, and amongst the weeds '*couch*' will probably be most abundant, and will yield a certain proportion of ash. The following is the analysis of such an ash, contaminated somewhat with clay which had adhered to the roots :—

Ash of Couch (*Voelcker*).

Potash	10·02
Soda	5·69
Chloride of sodium	3·34
Lime	5·58
Magnesia	·04
Oxides of iron and alumina	12·40
Phosphoric acid	9·38
Sulphuric acid	5·33
Carbonic acid	5·80
Soluble silica	24·92
Insoluble silica	17·50
	100·00

Thus the ash of couch contains a large proportion of phosphoric acid and potash, which are available for the growth of the turnip, but which were useless when combined with organic matter in the weed.

The effect of burning upon the inorganic matter of the soil, especially clay, is twofold: firstly, it alters its physical nature, which, from being tenacious, becomes friable and porous; secondly, it converts some of the insoluble mineral constituents, especially potash, into a soluble state. Hence burnt clay was frequently used as a manure. The reason of the change is as follows: clay contains a certain proportion of silicate of potash; upon burning in the presence of lime—and a sufficient quantity of lime to effect the change is generally present in soils suitable for burning—a silicate of lime is formed in place of the silicate of potash, and potash is consequently set free. Other substances besides potash are likewise set free, or rendered more soluble. The following results by Voelcker illustrate this:—

Effect of Heat on a Clay soil.

	Natural soil	Slightly heated	Strongly heated
Soluble portion	43·70	49·10	53·80
Insoluble portion .	56·30	50·90	46·20
Containing potash	(·35)	(·77)	—

Upon examining the ashes produced by the burning of the soil, the reason why paring and burning are so effectual becomes apparent. The following analyses made by Voelcker represent ashes where much soil was burnt with the vegetable matter, and also where but little soil was incorporated with the vegetable matter.

Ashes obtained by Paring and Burning.

	With much soil	With little soil
Moisture and water of combination	4·50	9·12
Oxides of iron and alumina	18·42	14·56
Carbonate of lime .	8·83	17·17
Sulphate of lime	1·15	1·73
Magnesia	1·76	·40
Chloride of sodium	1·03	·08
Chloride of potassium .	—	·32
Potash	1·08	1·44
Phosphoric acid	·71	1·84
Soluble silica .	—	8·70
Insoluble silica	62·52	44·64
	100·00	100·00

The vegetable ashes, or red ashes, amounted in the first instance to no less than 15 tons per acre, and the phosphoric acid they contained was equal to that contained in 7 cwt. of bone dust, and probably more than in 20 tons of farmyard manure. The value of paring and burning is due, then, to the great fertilising properties of these ashes. But it must also be remembered that, by destroying the weeds and noxious organic matters of the soil, its fitness for the growth of crops is materially enhanced.

Clay burning.—Upon some very heavy clay soils, even though free from weeds and organic matter, it has been found advantageous to burn the clay, because of the altered physical nature given to the same, as well as for the liberated potash, &c. Clays, however, are not suited for burning unless they contain silicates of potash ; moreover, the temperature at which they are burnt must be regulated ; if overburnt the good effects are neutralised. The clay must be burnt in contact with lime, which, if not naturally present in the soil, should be added to it before burning. The advantages derived are only partly similar to those obtained by paring and burning old pasture land. Turnips prove the best crop to grow after the burning.

CHAPTER VII.

THE IMPROVEMENT OF SOILS—*continued.*

The improvement of the chemical composition of soils.—In the course of a previous chapter it has been pointed out that the nearer a soil approaches a happy mixture of the four chief ingredients—sand, clay, lime, and organic matter—the more fertile the soil is likely to prove, the easier also will it be to cultivate, and the greater will be the variety of crops and live stock which it will carry. The question now arises, having a soil deficient in one or more of these chief ingredients, to what extent is it possible to supply them? The limit of possibility is wide, but the farmer has to consider expense, and it is the great expense attending the admixture of soils which places a limit upon the practice.

Taking these four ingredients in order, and assuming soils to be deficient in one of these constituents, to what extent and in what way can the desired constituent be supplied?

Soils deficient in sand.—There are three classes of soil liable to be deficient in sand: the heavy clay, the light calcareous soil, and the peat soil. To carry sand, the great weight of which has already been pointed out, and apply it to the land would be impossible, for the quantity so required would be immense; some other means then must be resorted to, and these are not applicable to calcareous soils as a rule. If the clay overlie a bed of sand, it is possible from time to time, and at no unreasonable expense, to dig into this subsoil and bring some to the surface. The expense and probable profit of the work depends on the depth to which it is necessary to go. This method is, as a rule, only applicable to heavy clay land. The second method is that of 'paring and burning' described in the last chapter. In the case of clay soils, the clay is converted partly into sand, further it loses its adhesive properties, and so acts as sand in its effect upon the surface soil. With peat land the organic matter may be burnt away, leaving the ash and mineral portion behind; this, consisting mainly of sand, is equivalent to sand that might have to be brought from a distance.

Soils deficient in clay.—Sandy, calcareous, and peaty soils are often deficient in clay. A small quantity of clay, however, has a wonderful effect upon these soils, and hence it is by no means a rare occurrence for clay to be brought and added to a soil. This practice is termed *claying.* According to the want of adhesive power in the land, so will be the amount of clay used, taking into consideration of course the distance the clay has to be brought. Owing to the large quantity of water clay retains, it should be carted as dry as possible, spread on the land in the autumn, and the winter allowed to act upon it and crumble it down before it is worked into the soil. Soils requiring clay are, on the one hand, peaty soils, such as are found in the fen country of Norfolk, many of which lands have been greatly improved by claying. Frequently the clay lies underneath the fen land, and it is brought to the surface then with comparative ease. The method employed is to dig deep trenches down into the subsoil, and bring up the clay to the surface; this is sometimes spoken of as *trenching*. Some light sandy soils, on the other hand, require clay, and are often so far distant from clay that its application is prohibited by the expense. In such cases the consolidation of the land is effected by the addition of organic matter in a manner to be now described.

Soils deficient in organic matter.—Such are especially very light sands and heavy clays, also calcareous soils. Organic matter in the shape of peat is never carried to the land. The most usual way to supply organic matter is by the application of farmyard manure, which being made largely of straw is of course composed mainly of organic matter. Another system, however, is to grow a crop of turnips, and to get this crop into the land.

If the soil be light, that is, a sandy, or calcareous soil, requiring consolidation, the land is 'folded;' that is to say, a certain number of sheep are let on to the land to eat up the turnips. The weight of the sheep is very great, and comes upon a comparatively small surface, hence folding is accompanied by a considerable consolidation of the soil, as well as enriching it with the droppings from the sheep. Not only is organic matter added to the soil by folding, but the want of clay where felt is somewhat made up for. Now on clay soils requiring organic matter folding is impracticable; they do not require the consolidating influence of the sheep, but the reverse. Hence it is customary to plough the turnips into the land, and by their decay to furnish the necessary organic matter. This is termed *green manuring*, because the crop ploughed in is invariably a green crop. Sometimes mustard or rape is substituted for turnips. While green manuring is absolutely necessary on heavy land, instead of folding, it is often practised upon light land, when folding is not convenient to the farmer.

Soils deficient in lime.—In the previous chapters, the value of lime as a constituent of the soil, in influencing both its chemical composition and physical properties, has several times been pointed out. One of the most perfect methods of improving land consists in adding lime to it; this is termed *liming*. The practice has been adopted for ages, probably long before science had explained the reason of its benefit. Unfortunately there is a tendency at the present day to neglect this method of improving the soil. Lime being of the four chief ingredients of soils the one least bulky, and least expensive, its use is attended with less trouble and cost than the preceding methods of improvement. If lime, however, is at times beneficial, it is not always so, and even upon land where in moderation it would be advantageous, its application is capable of being carried to excess. What soils then require lime? Soils which contain 2 per cent. of lime will not require to be limed unless it is for exceptional purposes. Soils which contain less than 2 per cent. and over ½ per cent. are for the most part benefited by liming, whilst soils containing less than ½ per cent. of lime demand lime before they can be profitably farmed. These figures are not absolute, for exceptions occur. Thus, soils containing over 2 per cent. of lime are sometimes benefited by liming, whilst others containing under 2 per cent. are not benefited. It will be seen that clays can receive with advantage, as also peat soils, a far larger quantity of lime than sandy soils.

Many substances are employed for the purpose of liming soils, each of which will have certain advantages and be suited to certain conditions. Of these substances the following are the principal:—

Slaked and unslaked lime.
Gas lime.
Chalk.
Shell sand.
Gypsum.
Marl.

Slaked and unslaked lime.—Limestone consists of carbonate of lime. Upon burning the limestone in kilns the carbonic acid is given off, and lime (caustic lime) remains. Upon mixing this caustic lime with water it becomes slaked, absorbs the water, swells up considerably in size, and easily crumbles to powder. This powder upon exposure to the atmosphere slowly absorbs carbonic acid, becoming again converted into carbonate of lime, but differs from its original condition in being now in a state of minute division. This state of division is such that it cannot be attained by grinding the limestone; moreover, the expense of grinding would be greater than that of burning in the kiln. There exist several kinds of limestone, some suited for building purposes, some for making hydraulic cement, some for mortar, and some for agricultural purposes. For agricultural purposes a limestone is required, the caustic lime from which will absorb a large quantity of water, and crumble down into a fine and bulky powder. The purer it is the better, for the lime is the only substance of value; hence everything else it contains detracts from its value. The small quantity of phosphoric acid found in limestones is not sufficient to affect their value.

The following analyses illustrate the composition of limestones, the first being good, and the second bad, for agricultural purposes:—

Composition of Limestones:—

	Good	Bad (magnesia limestone)
Lime .	95·01	60·05
Magnesia .	·10	30·02
Oxides of iron and alumina	·22	5·82
Alkaline salts, sulphuric acid, &c.	3·85	2 64
Silica .	·82	1·47
	100·00	100·00

The lumps of burnt and unslaked limestone are known as *shells*. The farmer buys these and carts them to his land. Here they are placed in large heaps, sometimes left uncovered, and sometimes covered with sods of earth and grass, this latter method being considered preferable. Slowly they attract moisture and slake, but they do not attract sufficient carbonic acid to become again converted entirely into carbonate of lime. The lime is allowed to slake until it falls easily to a fine powder. The composition of the spontaneously slaked lime will be approximately as follows:—

Slaked Lime (*Voelcker*).

Lime hydrate	83·43
Lime carbonate	15·11
Moisture	·78
Iron, alumina, magnesia, &c.	·54
Silica	·14
	100·00

This caustic or slaked lime was made from a very pure limestone, containing 99 per cent. of carbonate of lime. It will be seen that in the ordinary application of lime a large quantity of slaked or caustic lime is added to the land. Generally the slaking is sufficiently finished in the course of a month or six weeks, and the lime, now reduced to powder, is ready to be applied to the land. The time of year most suitable for this operation is the spring, before the application of artificial manures, and when there is no crop on the land. It must, therefore, be done either after wheat and before turnips, or after turnips and before barley. The lime should be at once covered up in the soil.

Gas lime is another substance used for liming. Caustic lime is employed at gas works to remove certain impurities from the gas, and when saturated, or nearly so, with these compounds is removed; it then constitutes gas lime. Its composition varies considerably. According to its dryness it may contain from one-third to half its weight of lime, that is, from 33 per cent. to 50 per cent.

The following analysis represents the composition of average quality gas lime:—

Moisture	28·75
Water of combination, &c.	1·50
Oxides of iron and alumina	1·90
Lime	38·86
Sulphuric acid, carbonic acid, &c.	28·29
Insoluble siliceous matter	·70
	100·00

The lime exists partly as caustic lime, but mostly as carbonate; there is also a considerable quantity of sulphide, sulphite, and sulphate of lime, the former of which become, when the gas lime is kept exposed to the air, converted into sulphate of lime or gypsum. Thus gas lime is somewhat similar to quick lime, and acts in a somewhat similar manner. It is necessary, before it can be applied to the soil, that it should be exposed to the air for some considerable time, so that the sulphide and sulphite of lime, which are injurious to vegetation, may be oxidised into sulphate of lime. Gas lime is best applied in the autumn, and the quantity applied per acre varies from 2 to 4 tons.

The action of quick, or caustic, lime differs from that of all other forms of lime applied to the soil. The effects are most powerful upon organic matter. It has already been shown how, by the oxidation of organic matter in the soil, organic acids are formed, and that these acids prove injurious to vegetation if they remain in a free state. The addition of caustic lime to the land neutralises these organic acids, and also facilitates their further oxidation and complete resolution into carbonic acid. At the same time the nitrogen which the organic matters contained, as well as their mineral constituents, are liberated. Consequently the beneficial effects resulting from the application of caustic lime are nowhere so marked as upon peaty or bog soils, and upon soils rich in organic matter.

The other substances used for adding lime to the soil are mostly and best applied to light soils.

Chalk is a soft kind of carbonate of lime found in several parts of England, and characterised by the presence of flints. It is divided into upper and lower strata. The latter frequently though not invariably contains phosphoric acid. When containing phosphoric acid it has been dug up and placed even upon chalk soils with advantage; phosphate of lime would now be used more economically.

The following analyses show the composition of chalks:—

Composition of Chalks.

	Upper	Lower	Red
Oxides of iron and alumina	1·05	·74	10·02
Carbonate of lime	97·20	98·22	80·04
Phosphoric acid .	·04	·08	—
Magnesia, alkalies, &c.	·25	·30	·66
Insoluble silicates	1·46	·66	9·28
	100·00	100·00	100·00

Shell sand is used largely in Devonshire and other places where limestone is not readily obtained. It varies considerably in composition, and in the quantity of lime it contains. To give the analyses of these shell sands is unnecessary, as they are composed almost entirely of carbonate of lime and silica. Shell sand should consist mainly of shells, but frequently it is largely intermixed with sand, and is then of far less value. A good shell sand should contain at least 50 per cent. of carbonate of lime; a poor one will often contain less than 20 per cent.

Gypsum, or sulphate of lime, is sometimes used as a means of giving lime to the soil, more especially for the growth of grasses, clovers, and mustard. Apart from the lime which it contains, there are no facts to show that it possesses peculiar properties.

Marls are, properly speaking, soils containing a large proportion of carbonate of lime. A marl, to be worth applying to another soil, should contain more than 10 per cent. of carbonate of lime. Marls are most suited for application to light sandy soils, upon which they have a very beneficial effect, due not merely to the lime they contain, but also to the clay generally associated with it.

These are the principal substances employed to convey lime to the soil. What are the effects produced? Lime may be applied with a twofold object. *Firstly*, as a means of improving the soil, which is the object in view in liming with caustic lime; and, *secondly*, as a means of replenishing the soil with the lime which has been taken out of it in the crops.

For liming, properly so called, the slaked lime is invariably used. Upon heavy land it may be used in a caustic state. Upon light land it should be applied after it has been allowed to stand some time to become mostly carbonated. Its beneficial effect upon soils containing organic matter has been pointed out. Liming also improves the physical condition of both light and heavy soils. Light soils it consolidates. Heavy clay soils it opens up and pulverises. This pulverisation is due to a chemical action exerted upon the clay. It has already been shown that in burning a heavy clay soil to bring about the disintegration of its silicates lime must be present, and it was stated that the burning resulted in an improved physical condition of the soil. It is found that caustic lime, even at the temperature of the soil, slowly causes the splitting up and disintegration of these silicates, liberates their valuable constituents, and improves the physical condition of the soil.

The crops which are mostly improved by the application of lime are those which contain most lime, namely, turnips, clover, and grasses. When lime is first applied to land, white clover generally appears in abundance. The corn crops are slightly benefited by the application of lime—barley probably more than the other cereals. The effect of lime in liberating potash from clay soils has caused it to be used with advantage for roots requiring much potash, and also for the potato, which crop it greatly improves. Flax is said to be in no way affected by the application of lime.

With regard to the frequency of the application of lime, and the quantity to be applied, it is somewhat difficult to lay down precise rules. Experience has taught that soils which require liming do so periodically, for the lime gradually sinks into the soil, and loses a great portion of its usefulness. The quantity will vary with the frequency of the application, being less the more frequently it is applied.

Frequency of liming.—The custom varies greatly from once in twenty years to as frequently as once in four or five. It is probable that while the one system errs on account of the distance between the applications, the other errs in the opposite direction. It has been pointed out that liming is best performed after the wheat crop, or rather before turnips. Now, if turnips are grown every fourth year, it will be well to apply lime every eight years, just before the next crop of turnips; where turnips come every five years, then lime may be applied once every ten.

The quantity of lime.—Lime is sometimes applied by the bushel, but more properly by weight. The largest quantity of lime applied is when land is first reclaimed from bog or waste, and is deficient in lime. It may be necessary then to apply as much as 10 tons per acre. In the ordinary liming of land this quantity is not needed, and 2 or 3 tons per acre applied every eight or ten years is ample. A ton of lime equals about 27 bushels, so that 60 to 80 bushels per acre ought to be used. The longer the period between the applications, the greater must be the amount applied. Hitherto the custom appears to have been to add for each year from 7 to 10 bushels of lime per acre.

As a means of returning lime to the soil, to replenish that which has been taken out by the crops, any of the substances previously enumerated may be used. This application of lime is necessary, because lime is one of the principal mineral substances upon which the plant feeds. The table on the following page shows the quantity of lime which average crops extract per acre from the soil.

Exhaustion of the soil by adding lime.—Just as plants require lime, so they require other substances. If, therefore, they are supplied with plenty of lime, and the land is improved in condition, and the crops increased in quantity owing to the vigorous growth induced, then the crops make an additional call upon the other constituents of the soil, until at last the soil may become exhausted of one or more of its valuable constituents. This must be guarded against, otherwise the application of lime will be the means of exhausting the land.

Lime in principal Farm Crops.

	Name of crop	Weight of crop	In lbs., per acre		Total
			In grain or bulb	In straw or leaves	
Grass and leguminosæ	Meadow hay	$1\frac{1}{2}$ ton	—	—	28·1
	Clover hay	2 tons	—	—	86·1
	Beans	30 bushels	2·9	30·2	33·1
Roots and tubers	Potatoes	6 tons	2·9	22·7	25·6
	Swedish turnip	20 tons	28·1	32·4	60·5
	Mangels	30 tons	33·0	39·7	72·7
Cereals	Wheat	30 bushels	1·0	9·2	10·2
	Barley	40 bushels	1·3	8·5	9·8
	Oats	45 bushels	2·0	9·8	11·8

In speaking of the general examination of a soil, it has been mentioned that soils which have been limed are seen to have large pieces of lime, still unbroken, and only slightly attacked by water, lying at a considerable, but uniform, depth in the land. It is evident, then, that in liming a soil the greatest care should be taken to apply the lime in the finest state of division possible. This may indeed be laid down as a principle and rule to be followed in the application of every description of material to the soil.

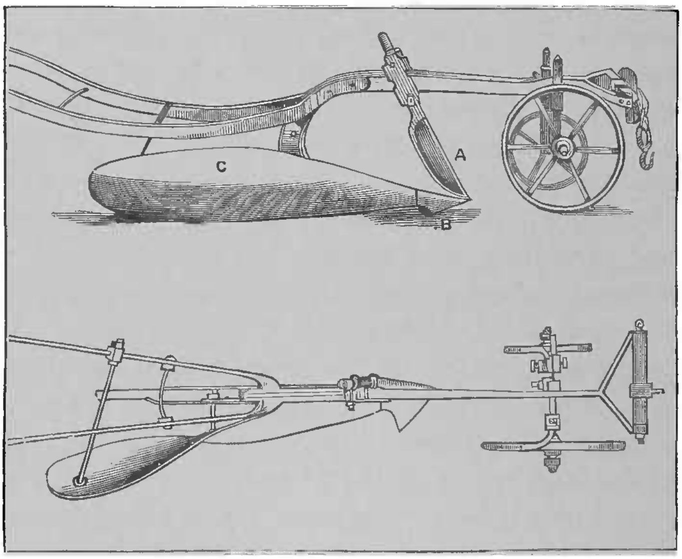
CHAPTER VIII.

THE CULTIVATION OF THE SOIL.

THE cultivation of the soil is the means by which its physical condition is made most suitable for the growth of plants. Before the land is fit for the reception of seed, it is absolutely necessary that the surface soil be brought into a more or less fine condition. And as the roots of plants need to penetrate the subsoil in order to obtain the necessary food for their sustenance, the subsoil also must be brought to such a consistency as will permit the roots to force their way into it. Even upon soils not too hard to allow the roots of plants to penetrate them, the loosening of the subsoil may be advisable or even necessary so as to facilitate natural or artificial drainage. In cultivating the soil, then, the object of the farmer is twofold. Firstly, to break up the subsoil without displacing it; and, secondly, to bring the surface soil into a fine state of pulverisation, by exposing every part of it periodically to the action of the atmosphere and other weathering agents.

The implements employed by the farmer to bring about these results, though not very numerous, are nevertheless of great importance, and as the preparation of the land is termed tillage, so these implements are spoken of as tillage implements.

The plough.—Everyone has a slight notion of what a plough is, but everyone may not know what are the different kinds of ploughs, what constitutes a good plough, and the exact nature of the work which each ought to perform. The plough has been known from the earliest times. The Egyptians, the Greeks, the Romans, all used ploughs of one form or another. That of the present day, however, bears little resemblance to those of ancient or even



modern times, more especially in this one striking point, that the plough of the past was made mostly of wood, only slightly of iron; the plough of the present day is made entirely of iron. The plough may be described as an instrument for cutting a strip of earth, and turning it completely over on to its face. It has, therefore, two essential parts, the one for cutting the earth, the other for turning it over.

The cutting part consists of two pieces, one of which is termed the *coulter* and the other the *share*. The coulter (*a*) is a long, strong knife which cuts the soil vertically; the share (*b*), a broad, triangular, and flat knife which cuts the soil horizontally. In the best ploughs these are placed at right angles to each other. As the plough passes over the ground a strip of earth is thus completely cut away. The second part of the plough, termed the '*mould board*' (*c*), is destined to receive this cut strip of soil and to turn it completely over, or else to place it on its side. In the former case the top-soil becomes buried, and the under-soil brought to the surface. The mould board is attached to and continuous with the share. These three essential parts fixed to a strong light beam, to which the horses are attached to draw the implement along, and with two long handles projecting behind by which a man who guides the implement may regulate the work done, constitute the simple plough. The long hollow cut left in the ground, after the plough has passed along it, is termed a 'furrow,' and the long line of upturned earth is termed a 'ridge.' One of the main points in the plough is the shape of the mould board, because upon its shape will greatly depend the difficulty of drawing the plough; hence it is essential that the mould board should cause the smallest possible resistance to the draught of the plough, and so entail a minimum of exertion upon the horses. Generally speaking, the longer the mould board the less the resistance. Above all things it is of importance that the work done by a plough be done well. As in the simple plough just described, this depends almost entirely upon the man tending it—that is, guiding it; every facility should be given him in the construction of the implement. To this end the beam in front of the coulter is as short as possible, while the handles are as long as possible. Such is the simplest plough. It is steadied only by the man who holds it, and in spite of the greatest care it will be sure to swing from side to side as it works, hence it has been termed a 'swing' plough. To prevent this swinging, which spoils the work, it is now customary to place two wheels, one large and one small, in the front of the plough. The small one works on the surface of the uncut ground, the large one in the last furrow. Such a plough is termed the 'wheel' plough. Not only do the wheels steady the plough, but they regulate and keep regular the depth of the furrow, and they save the man tending the plough a deal of labour. Consequently, for all general purposes, the wheel plough has superseded the old swing plough, which is now used only upon very rough and uneven ground. The simple plough makes one furrow. To save time and trouble ploughs have been constructed having double or triple parts, and therefore capable of making two or three furrows at the same time. Only on very light land can such ploughs be worked by horses.

Weight of ploughs.—According to the nature of the land to be ploughed so will be the strength of the plough requisite, and corresponding therewith will be the weight. Now, the greater the weight to be drawn the greater the labour, and it is essential in farming to economise labour; hence the farmer must never use a heavy plough where a lighter one would do the work, and hence, also, the necessity of having ploughs which combine strength with lightness. The weight of a plough for light land should not exceed 2 cwt., for medium land 2½ cwt., and for heavy land 3 cwt. The double and triple ploughs above mentioned should not weigh more than 4 cwt. and 6 cwt. respectively.

Depth of ploughing.—The depth at which the plough works in the soil varies chiefly with the nature of the soil. In light soils the furrows are cut from 4 to 7 inches deep, in heavy soils from 6 to 10. It is not well to plough land too deep, especially after previous shallow ploughing, lest a poor subsoil be brought to the surface, while a rich surface soil be buried. A furrow of about 7 or 8 inches deep is ample for all ordinary purposes. On the other hand, it is not well to plough at the same depth from year to year, and it is the custom, and advisable, to plough occasionally half an inch or one inch deeper than usual. This deep ploughing must be done in the autumn.

Width of furrow slice.—The width of the furrow slice is generally greater than its depth. With a depth of 6 to 8 inches the width would be from 8 to 10 inches. Sometimes, as in the Tweedale plough, the depth and width are practically the same.

Points of a good plough.—From the preceding it will be evident that the differences between a good and a bad plough lie not in one point only, but in many. Of primary importance will be the efficacy of the work done. This consists in the plough turning over the cut furrow slice at a regular angle and packing it—or pressing it, on the previous furrow slice—in leaving the sole of the furrow perfectly flat, and the land side clear and true, thus furnishing plenty of space for the horse walk during the cutting of the next furrow. The strength of the plough and its mechanical qualities, combined also with simplicity of construction, must next be taken into consideration. Finally, a plough should be light in weight, easy of draught, and inexpensive.

There are several moot points in connection with ploughing which may here be mentioned.

First, it has been stated that each furrow slice should be well packed against the former furrow slice. This necessitates the slice remaining unbroken. Now on the Continent it is considered best, as the furrow slice falls over, to thoroughly break it up, and not to leave it unbroken according to our English method. Which is the better plan it would be difficult to prove; probably the English for autumn ploughing, the foreign for spring ploughing.

Secondly, considerable diversity of opinion exists as to whether the furrow slice should be rectangular or trapezoidal; but as the rectangular furrow slice gives less work to the horses, without diminishing the value of the work done, it is probably the more useful.

Thirdly, what is the best angle at which the furrow slice should be left, when turned over? If the chief value of ploughing is due to the subsequent weathering of the soil, as is believed, it is evident that, the greater the surface of soil left exposed, the more complete will this action be. The angle at which this is accomplished, and therefore generally regarded as most advantageous, is that of 45° This assumes the furrow slice to be a little wider than it is deep. By making the width double the height, a less surface would be exposed, but there would be a considerable saving in time and labour, which by some is considered to more than compensate for the loss of surface exposed.

Fourthly, the shape of the mould board which, as previously stated, is the most important part of the plough, has naturally raised a deal of argument and diversity of opinion. It is a complicated question, suitable only for the mechanical engineer. But the final test of its efficacy, and the one of primary importance to the farmer, is the effect which the shape of the mould board has upon the draught of the plough, whatever increases the draught being essentially a drawback.

There are a few points in connection with the ploughing of land which may perhaps be best considered here. As the sowing of seeds generally follows the ridges formed by the plough, the question arises, Does it signify whether the seed be sown in lines of one direction rather than another? It does. For instance, if seed be sown in ridges lying from east to west, when the corn has risen to some height the sun will have comparatively little effect upon the soil—all its heat will fall upon one side of the corn only But if, on the contrary, the seed be sown along ridges running north and south, then the sun shining down the rows of plants will warm the soil and promote growth. Hence, plough ridges, where possible, north and south. For the preparation of the ground to receive the barley crop it is customary to plough the land twice; in the first instance in the autumn, as soon as the sheep have cleared off the turnips, and, secondly, before the sowing of the barley in the spring. This second ploughing is done at right angles to the autumn ploughing, and is called 'cross ploughing.' From what has just been stated, it is evident that this second or spring ploughing, as it will determine the position of the barley, should be from north to south, and that the winter ploughing should be from east to west.

With this exception for barley, ploughing is generally performed in the autumn; and, when the object of cultivation is considered, it is easy to see that the autumn is the best time for ploughing the land, for it enables all the weathering effects of the winter's cold to act upon the soil. Many difficulties frequently arise before the land is in a fit state to plough; thus land should never be ploughed when wet, more especially clays, nor should the soil be too dry so as to fall to pieces off the mould board.

A plough which, instead of throwing the earth on one side only, has two mould boards placed back to back, and throws the earth on both sides simultaneously, is called a 'ridging' plough; by such a plough ridges are thrown up for the growth of crops, such as potatoes, &c. There is one other plough which perhaps ought to be mentioned, called the 'one-way' or 'turnwrest' plough. It is not much used except in hilly districts, where it is necessary that the furrows should all be turned in one direction. This is accomplished by attaching to the plough two mould boards, working round a central bar, and capable of being used alternately, the one made to throw the earth to the right, the other to throw it to the left. The one mould board replaces the other when the plough is travelling backward, becausct he furrows have to be thrown alternately to the right and left of the beam. And as it is also necessary that the coulter should pass to the opposite side of the beam, in the best one-way ploughs the turning of the mould board also adjusts the coulter.

The ploughing of heavy land, such as clay soils, will not only require a heavier plough, but be far more difficult work. Consequently, upon heavy land, the use of steam as a motive power by which to draw the plough has become very general of late years. But the power of steam is so much greater than that of horses, that it is found possible to use ploughs which cut not merely one furrow, but several furrows at the same time. As these ploughs cannot turn round they are made double, and while one half of the plough is cutting, the other half is up in the air; upon reaching the end of the furrow this second part is brought down into the ground, and the former part swung up out of work.

It has been shown why it is not well, as a rule, to bring up the subsoil to the surface. In rare instances upon alluvial soils the reverse holds good, the land is then deeply ploughed. This is called 'trench' ploughing. Even on land where the subsoil cannot be brought to the surface, and especially on heavy clay lands, it is of advantage to move the subsoil and make it as light and open as possible. To perform this, ploughs are made called subsoil ploughs, but as the moving of the subsoil is seldom necessary on light land, most subsoil ploughs are fitted only for steam cultivation. They consist essentially of a broad horizontal knife-edge, passing through the ground parallel to the surface, and sloping slightly upwards at the base. This penetrates the soil to a depth of from 6 to 12 inches beneath the ordinary plough-share, making in it a triangular cut and slightly raising the soil, which immediately afterwards falls back again into its original position, but in a more or less pulverised condition. For use on lighter land the subsoiler is sometimes attached to ordinary ploughs, or to double-furrow ploughs in place of the foremost plough. When performed by horse-power, subsoiling is sometimes done by a separate machine immediately in the wake of the ordinary plough. 'This system is attended with the disadvantage of employing two sets of men and horses, besides which the pan of the furrow is twice trodden by the team.' The best plan undoubtedly is to use the double-furrow plough with the subsoiler in the forepart. A good subsoil plough will possess the same qualities as a good ordinary plough so far as they are applicable.

The cultivator.—This implement is next in importance to the plough. It is also called the grubber, scarifier, or broad-share, according to slight alterations in its construction. It consists of a heavy iron frame resting on three or more wheels. The frame carries teeth, or tines of iron curved so that they enter the soil at an angle; by simple mechanical means the inclination of this angle can easily be altered. The tines come to a sharp point, and upon these points various shaped teeth can be fixed. It is according to the shape of these teeth that the change in name of the implement depends. Such an implement will stir up the ground to nearly the same depth as a plough, without, however, turning it over; it will drag out of the ground the roots of weeds instead of cutting them as does the plough, and is consequently found of great value in clearing land, and in removing that greatest of all weeds, couch grass. Consequently it is used in the autumn, before ploughing, to clean the land, and again in the spring to break up the autumn-ploughed soil. The effect of the plough and cultivator will be to break up the soil into large masses. For the further pulverising of these masses two kinds of implements are used: harrows and rollers or clod crushers.

Harrows.—There are three kinds of harrows, which besides pulverising the soil are also employed for covering up the seed after it has been sown. The harrow consists, like the cultivator, of an iron frame carrying teeth, but differs from it in not being supported by wheels, so that the work it performs depends very greatly upon its weight. Formerly, another distinction existed between the cultivator and harrow—the former having curved tines, the harrow straight; and it would be well if this distinction still held good. But there is an implement named the chisel harrow, which truly is neither a harrow nor cultivator, though generally classed among the former, as it performs work similar to a heavy harrow.

The best form for the frame of the harrow is a zigzag. The teeth should be straight and wedge-shaped at the point. No two teeth should pass over the same ground, and the teeth, by being alternate, should be separated as far from each other in every direction as possible, for this prevents the implement becoming clogged. Harrows, like other implements, must vary in weight according to the nature of the land. For brushing in grass seeds and for use on grass land light harrows are used, which consist of a series of iron chains linked together. These are termed *chain harrows*. The part which operates is the under surface of the links. Chain harrows are also made having small teeth, or tines, projecting from the chains. These are applicable to rougher surfaces than the simple chain harrow is suitable for.

Rollers.—For the purpose of breaking the clods which may remain on land after its treatment with the implements previously named, several kinds of rollers are used, whilst others are used for pressing down and consolidating light land either before or after seed has been sown upon it. For the latter purposes the roller proper is used, consisting of a cylinder either in one or two parts, and about 6 feet long. The lightest are made of wood, and the heavy ones used to be made of stone, but iron is now superseding this material, it being possible to make them of any size or weight, suitable for the work they have to perform. It is a mistake to increase the weight of a roller by placing stones or other heavy weights upon the frame.

The *clod crusher* differs materially from the roller. It was found that a heavy roller, instead of breaking the clods, sometimes pressed them into the ground and also became clogged. The clod crusher, to overcome this, is made of a number of heavy iron wheels moving loosely round a common axle, each wheel being fluted, or shaped like the wheels of railway carriages. Other clod crushers have these wheels serrated instead of fluted. Besides being used on heavy clay land to crush the hardened soil, clod crushers are frequently used on light sandy soils to consolidate them, and for other purposes.

Such are the tillage implements used in the cultivation of the land. While they confer great advantages upon the physical character of the soil, they also clean it of weeds, and prepare it for the seed. A fine, moist, deep, and clean surface soil is necessary for the reception of the seed, and it is by the judicious use of tillage implements that such a seed bed is obtained.

It would be impossible in these chapters to enter fully into the mechanical principles which govern the construction of farm implements. At the same time one or two points of special importance may be mentioned. Firstly, 'Of all simple geometrical figures the triangle is the only one which cannot alter its form without at the same time altering the dimensions of its sides, and which cannot therefore yield except by separating at its angles or tearing its sides asunder; hence, therefore, a triangle whose joints cannot separate, and whose sides are of sufficient strength, is perfectly rigid.' It is for these reasons that in all well-made farm implements the parts are combined so far as possible in triangles. Secondly, owing to the cohesive force of iron, this substance should always be used to 'tie,' or bind together, parts which are liable to be pulled asunder. Where, however, two parts are liable to be forced together iron would not have the desired effect of keeping them apart or 'struting' them, as it would be liable to bend. Here wood, which weight for weight has much more breadth than iron, ought to be used. By attending to these and similar rules, implements are now made devoid of that cumbrous weight and needless strength which they possessed in days gone by

CHAPTER IX.

THE ATMOSPHERE AND SOIL AS PLANT FOOD.

In the previous chapters we have considered the soil and its preparation for the sowing of seed. If we place a seed, say of wheat, into a fertile soil, and it receives a moderate quantity of heat and moisture, it rapidly increases in bulk and weight, whilst it undergoes those changes called growth. If at the end of the period of growth we reap the corn which has grown from this seed, how great is the quantity of matter we then have compared with what we originally had in the seed! In this chapter some endeavour will be made to show where this matter has come from, leaving to another chapter the why and wherefore of the processes involved. Before stating its source, however, let us endeavour to realise what it consists of. If we take this full-grown plant and dry it, we shall find that it will lose the greater proportion of its weight. A turnip, for instance, will lose 90 per cent. of its weight. This loss is water, and water constitutes the greater portion of all plants. The dry solid matter if heated to redness will mostly burn away, but not completely, there will still be left a small quantity of matter which will not burn away; this is the *ash*, or *mineral matter*, of the plant. The portion burnt away is its *organic* matter, and consists mainly of carbon. It will also contain nitrogen, hydrogen, and oxygen. The ash, though small, is highly complicated, consisting of a variety of substances, which, small though they are in quantity, yet are, nevertheless, of vital importance. If the plant were unable to obtain any single one of these substances it would not grow. This, the most important fact in connection with plant life, is the basis of one great division of scientific agriculture, and must be particularly remembered. It is one of the primary discoveries of modern science. The composition of the ash left by burning various plants has been thoroughly investigated by Way and others. It is found that, as a rule, the following substances are present in varying proportions in the ash of most plants: silica, lime, magnesia, iron, potassium, and sodium, combined with phosphoric acid, sulphuric acid, chlorine, and carbonic acid. Whether the carbonic acid exists as such in the plant, or whether it is the result of the combustion necessary to obtain the ash, is difficult to say. If the quantity of mineral matter in the plant is small, yet the total quantity present in a crop is considerable. The following table will give an approximation to the quantity taken up by ordinary crops from one acre of soil in a year. The figures are the mean results of several analyses, and do not represent anything like large crops, but, as may be seen, only medium crops.

From whence do these substances come? So far as is known at present, all plants take the moisture they require from the soil, and not from the atmosphere. The rain which falls wherever a crop is grown will more than supply all the water in that crop. In other words, the water which forms so large

Composition of Crops.

	Swedes, 14 tons	Barley, grain, 40 bushels, and straw	Clover hay, 2 tons	Wheat, grain, 30 bushels, and straw
	lbs.	lbs.	lbs.	lbs.
Weight of crop	36,064	4,527	4,480	4,958
When dry	4,055	3,827	3,763	4,183
Moisture	32,009	700	717	775
Organic matter	3,817	3,681	3,508	3,994
Nitrogen	102	47	102	45
Mineral matter (ash)	238	146	255	189
Containing :—				
Silica	6·7	63·5	6·8	111·1
Lime	42·4	9·8	86·1	10·2
Magnesia	9·2	6·5	30·9	7·7
Potassium oxide	79·7	31·4	87·4	27·9
Sodium oxide	32·0	5·2	4·1	3·4
Phosphoric acid	21·7	20·6	25·1	22·7
Sulphur	17·8	6·1	9·4	7·8
Chlorine	15·1	3·6	9·4	1·9

a proportion of all plants is absorbed by them entirely through their roots. There is certain evidence, to which your attention was drawn in a previous chapter when treating of evaporation from soils, to show that plants absorb by their roots a quantity of water far greater than they require to store up in their tissues, and that the excess is given off from their leaves. It is probable that a small quantity of mineral matter held in solution in this water enters the plant, whilst it is certain that this mineral matter could not again leave the plant by the water evaporating from it; thus, a small amount of mineral matter would accumulate in the plant. There is, however, reason to believe that all the mineral matter is not so attained, though one thing is certain, that is, that all the mineral constituents of the plant come to it from the soil. Hence it is that a soil deficient in any one of the essential mineral constituents of the plant is barren.

Now, as to the organic matter: from whence come the carbon, nitrogen, oxygen, and hydrogen, of which this is composed? It was formerly supposed that the plant was capable of absorbing organic compounds direct and ready formed from the humus, or organic matter contained in the soil. This idea is now considered to be erroneous. The plant has no such power. But it has been already pointed out that the final state of this organic matter after its complete oxidation is carbonic acid gas, and that the air contained in the soil is rich in this gas. There can be little doubt that this carbonic acid enters the plant by the roots, dissolved in the water of the soil. Whether the roots have the power of absorbing the carbonic acid, as a gas, is not certain. This carbonic acid is a compound of carbon and oxygen, and plants obtain in this way a small part of their carbon. In a similar manner plants obtain a portion of their nitrogen from nitric acid, which compound of nitrogen and oxygen has already been shown to exist in all fertile soils. It is absorbed by the roots of plants, probably in combination with potash. The whole of the nitrogen which enters the plant from the soil is most likely absorbed as nitric acid. Water being a compound of hydrogen and oxygen, it is possible for the plant to obtain the four chief constituents of its organic matter, viz.: carbon, nitrogen, oxygen, and hydrogen, from the three substances, carbonic acid, nitric acid, and water present in the soil.

The soil might thus appear to supply the whole of the organic constituents of the plant. But it does not. The plant lives mainly, and depends for the greater portion of its organic matter, on the atmosphere. Every man and all animals live by breathing; in doing which they take into their lungs oxygen, and give off carbonic acid. But if we compare the composition of our atmosphere to-day with that of the atmosphere of, say, a century ago, we find there is no material difference in their composition. Speaking roughly, it was then and is now a simple mixture of the two gases oxygen and nitrogen, in the proportion of 21 parts of oxygen to 79 of nitrogen. It is only by most careful operations that the presence of carbonic acid can be detected in it at all, and the quantity found upon analysis amounts merely to ·04 per cent. or less. What, then, has become of the carbonic acid which during the intervening century has been formed by man and animals? Experiment has proved beyond doubt that plants have absorbed this carbonic acid. It is found that all plants having the green colour of ordinary leaves, which colour is produced by a substance called *chlorophyl*, have the property of absorbing carbonic acid gas through the organs containing this chlorophyl, or mostly through the leaves. The plant does not retain the carbonic acid, but splits it up, retaining the carbon which it requires, and giving back to the atmosphere the oxygen which is so essential to man. Thus the wonderful balance of nature is incessantly maintained.

The oxygen of the atmosphere plants absorb, so far as we know, only to a slight extent. The oxygen which they require is probably obtained from water.

Every attempt to show that plants absorb free nitrogen from the atmosphere has failed. This simple statement is one which by many would be warmly contested; but this is not the place to enter into the long and conclusive series of experiments which justify the statement. There are, however, several questions in connection with the nitrogen of plants, and how it is obtained, which here need exposition.

Let a soil be analysed, and the total quantity of nitrogen it contains estimated; then let a crop of clover be grown upon it, and, after the crop has been cut, the nitrogen again estimated. In the crop there will be taken off from the field say, according to the table, 102 lbs. of nitrogen, and yet the soil will subsequently be found to contain as much, and probably more, nitrogen than it did before the crop of clover was grown. Why is this, and where has the nitrogen come from? This is one of the problems of modern agriculture, because nitrogen is an essential constituent of the most valuable of the organic matters in plants, viz., albumen. From albumen and similar nitrogenous compounds in the plant the flesh of animals is built up; hence the presence of these nitrogenous compounds in a plant determines its value as a food. In endeavouring to answer the question where the nitrogen comes from, it will be taken as proved that no plant can absorb free nitrogen. The nitrogen which comes to the soil may come from beneath upward to some extent; but we are driven to the conclusion that the main source of this nitrogen is the atmosphere. Hence the question arises —Does the atmosphere contain nitrogen in any form besides as a free gas? Analysis shows that it does. The atmosphere contains minute quantities of ammonia, nitric acid, and organic matter containing nitrogen. The quantities are most minute. Nevertheless it is probable that the relation between the nitrogen existing in the air as ammonia, &c., and the carbon existing in the air as carbonic acid, is not less than the relation between the nitrogen of plants and the carbon of plants. The theoretical conclusion is thus forced upon us that the amount of nitrogen compounds existing in the atmosphere is quite sufficient to account for the nitrogen in plants. Are there any practical proofs of this? Firstly, if this nitrogen exists as ammonia in the air, owing to the solubility of ammonia in water we shall expect to find it in rain water. Upon analysing rain water it is found to contain and to bring to the soil nitrogen, not merely in the form of ammonia, but also as nitric acid and as organic matter.

The following table well illustrates this, and gives the maximum, minimum, and mean of 69 samples of rain water analysed:—

Nitrogen, in parts per million, existing as:—

	Total nitrogen	Organic matter	Ammonia	Nitrates
Highest	1·94	·66	1·28	·44
Lowest	·13	·03	·04	·00
Mean	·70	·19	·37	·14

These results were obtained at Rothamstead, in England, by Messrs. Lawes and Gilbert. Dr. Angus Smith made similar experiments, and obtained far larger amounts, the quantity increasing as the neighbourhood of towns was approached. Experiments have also been made abroad with similar results. Thus it is proved that the rain which falls upon a country place brings to the soil in the course of a year from 8 to 10 lbs. of nitrogen, while as towns are approached this quantity increases. But it is not always raining. Is then the nitrogen brought down by rain the accumulation of what has been given off during the dry season intervening since the last rainfall? At first one might be led to think so, for experiments prove that the nitrogen decreases as the rain continues—that is to say, the first few hours' rainfall washes the atmosphere clear of these nitrogen compounds. This, however, is local in its action. At times when there is no rain plants are covered with dew or hoar-frost. What quantity of water is gained by the plants and the soil in this way does not greatly signify, and cannot easily be shown; but what is of more importance is the fact that this water contains nitrogen. Dew, like rain, has been proved to contain nitrogen in three forms. The following table illustrates this, and gives the maximum, minimum, and mean of 7 analyses:—

Nitrogen, in parts per million, existing as:—

	Total nitrogen	Organic matter	Ammonia	Nitric acid
Highest	4·55	1·96	2·31	·50
Lowest	1·66	·26	1·07	·28
Mean	2·79	·76	1·63	·40

It will be seen that the quantity of nitrogen in dew is four times as great as in rain water. The amount of water which is precipitated upon an acre of land under cultivation as dew in a year must be considerable, and also the quantity of nitrogen which it will take to the soil. Probably it is more than that taken by rain. The various means by which the soil may obtain its nitrogen have not as yet been exhausted. If an atmosphere containing ammonia be passed over a lump of soil slightly damp, that soil will extract the ammonia from the atmosphere. Experiments have recently been made in Germany, which show that the soil gains by this property a large quantity of nitrogen from the atmosphere. According to the experiments of Heinrich, a square metre of soil received by rain ·706 gramme of nitrogen, but by absorption from the atmosphere 3·066 grammes. If we calculate these quantities per acre we find that in the rain the land obtained 6·2 lbs. of nitrogen, which corresponds fairly well with the results of Messrs. Lawes and Gilbert, and that by absorption it obtained in the form of ammonia alone no less than 27 lbs. of nitrogen. Turning back to the table of nitrogen in rain water and dew, it will be seen that only half the nitrogen exists as ammonia. Thus a field of one acre absorbs or receives either directly from the atmosphere, or else in rain and dew, a very considerable quantity of nitrogen—this is a rational solution of the so-called nitrogen question. Is it possible that the atmosphere could contain sufficient nitrogen in these forms? The question is best answered in this way: a crop of clover will absorb from the atmosphere about 2,400 lbs. of carbon, and it is proved that for this purpose there need be, and is, in the atmosphere no more than ·04 per cent. of carbonic acid, which is equal to about ·01 of carbon. Now, presuming the same plant absorbed the whole of its nitrogen from the atmosphere as ammonia, it would need about 120 lbs. of ammonia, or

$\frac{1}{20}$th part of the quantity of carbon. Presuming the ammonia to be as effective as the carbonic acid, then the presence of ·0005 per cent. of ammonia in the atmosphere would be sufficient to meet this demand. There cannot be the slightest doubt but that this quantity of ammonia exists in the atmosphere.

The mineral food of plants.—Of the mineral constituents of the plant, the soil generally contains sufficient. Lime, as previously stated, is sometimes absent, and when absent it must be applied to the soil. The same also may be said of potash.

Of the acids, by far the most important is phosphoric acid. When absent from a soil it must be supplied, for it forms an important constituent of all crops, and without its being present in ample quantity no crop will attain perfection. Sulphuric acid is sometimes absent from a soil, yet it is undoubtedly a necessary substance to be present, for not only is it found in plants as sulphuric acid, but it is the source of the sulphur which is contained in the organic matter of many plants, and especially in those belonging to the order leguminosæ; hence such plants—for example, clovers—are benefited by the application of a substance like gypsum containing combined sulphuric acid.

Thus the atmosphere and soil supply all the substances necessary to build up the plant both in its organic and mineral constituents. It has been shown, in a previous chapter, how soils wanting in any of the essential mineral constituents of plants are not fertile, consequently the farmer makes a point of supplying the desired mineral substance before he commences to cultivate his land.

But this alone is not sufficient to maintain the land in good condition, as a moment's consideration will demonstrate, for, when we consider that the bones of animals consist mainly of phosphate of lime, and that these bones have been formed out of material gained by plants from the soil, it will be easily realised that a large amount of phosphate of lime is yearly taken out of a well-cultivated soil by the crops. From the same cause the soil suffers yearly a loss of nitrogen, of potash, and of other mineral constituents. If the fertility of the soil is to be maintained, as under good management it should be, then the farmer must return to the soil, in some cheap form, the substances which he has taken out of it in his crops. Whatever he employs for this purpose is termed a manure.

CHAPTER X.

FARMYARD MANURE.

In every farm there will slowly accumulate during the autumn and winter months a considerable quantity of farmyard manure, consisting of the droppings of the animals of the farm combined with the litter upon which they are kept. Besides this solid dung there will also be a certain quantity of liquid manure not absorbed by the litter, but finding its way into the drainage of the yard. These two substances combined, solid and liquid manure, may be termed the natural manure of the farm, and it is doubtful whether any artificial manure is so cheap and so useful to the farmer as farmyard manure. It requires, however, careful management, and only by such management is its value retained. There are three points in connection with farmyard manure which require study: its management, its composition, and its use.

The management of farmyard manure.—In a well-managed farm the litter of the various animals will be carefully changed as occasion requires; the dung which is made may be treated in various ways.

First, where the manure is removed. When the manure is required in the winter it will be carted direct from the yards to the fields, and ploughed in shortly after being put on.

In other cases, and where required for spring dressing and in a rotten condition, the manure has to be kept during the winter. This may be done in several ways.

The oldest method, and still the most frequent, though not the best, is to cart the manure to the field or fields upon which it is subsequently to be used, and there to make it into a 'manure heap.' In choosing a place for the manure heap, regard should be had to the future carrying of the manure on to the land. It should therefore be, where practicable, on the highest ground in the field, provided this does not entail the carrying of the manure too great a distance from the cattle sheds, nor over the ground that will be afterwards manured. Subsequently, when the manure is spread on the land, the horses will have to work down-hill with their loads. The field chosen for the first dung heap should be that upon which the dung will be first required, and no more dung should be put into that heap than will be required for the field.

The dung-heap gradually subsides, so that one of 4 to 5 feet in height will sink to about 3 or 3½ feet. The ends of the heap are trimmed square, and the whole is then covered with soil to keep out the rain, and to keep in the volatile products resulting from the fermentation which goes on in the heap. This fermentation causes a large amount of liquid matter to be formed which gradually soaks to the bottom, oozes out of the heap, and runs away. The analysis of this black liquid shows it to be the most valuable part of the manure, hence the first object of the farmer should be to preserve it.

To this end the manure heap should rest upon an impervious foundation, for which clay is well suited. Upon this should be placed several inches of rubbish (dead leaves, cinders, and other absorbent substances), which will, to a certain extent, retain the liquid. Should any liquid escape this, it must pass into a trench surrounding the dung heap, and be led into proper receptacles. If the dung be intended for use in the spring, it is usual to turn the whole of the heap well over once, about a month before it is required for use. To turn it more than once is needless, entails useless labour, and causes the manure to lose its value. In fact it is doubtful whether the expense and trouble of turning the heap at all are not time and labour lost. Such is one method of treating farmyard manure.

The other methods of treating farmyard manure may be divided into two classes, depending upon whether the manure is removed from the animals as it is made, or not. Thus it is sometimes the custom to allow the cattle to remain on the manure, treading it down into a solid mass, they being supplied with fresh litter as often only as is necessary to give them a dry footing. This manure is usually made in a yard, and this is why it is termed farmyard manure. When not allowed to remain under the animals, the manure is removed from time to time, and stored away in a separate shed, or, better, in a well-constructed, water-tight, and covered pit. In these pits all the dung from the various animals becomes mixed together, this being by many farmers considered the most advisable practice. The great object to be attained in preserving dung is to keep the soluble constituents from being washed out of it. Whether, therefore, the manure be left under the animals in the yard, or removed from day to day, it is essential that these yards should be completely covered, and that the rain in running from the roof should be carried away, and not allowed to mix with the drainings from the manure. The manure made in the farmyard will be produced by animals receiving ordinary diet, and more or less free to move about. Fattening animals, which are receiving a highly nutritious diet, so that their manure is the most valuable of any made on the farm, are generally kept in stalls or pits. The floor of the stall is level with the ground, but the floor of the pit is several feet below the ground. When the animals are in stalls the manure is generally removed from beneath them and stored separately. When the animal is in a pit the manure remains beneath it, sufficient straw being added from time to time to keep the footing tolerably dry. Thus the animal and manure gradually rise, until the latter is level with the surface of the earth.

There are two results which make the covered yard more advisable than the open for the production of farmyard manure. Firstly, experience and analysis both show that the manure made under cover is worth about half as much again as manure made in the open; and, secondly, at least fifty per cent. less straw is required for litter in a covered yard than is needed in an open one. Moreover, the necessity of turning the manure becomes less frequent, and the operation less arduous.

The composition of farmyard manure depends upon many circumstances, and will vary with each.

Firstly, the kind of animal which makes it—whether it be horses, cattle, or pigs. Sheep manure, being for the most part left on the land, will be treated of hereafter; it does not affect farmyard manure as a rule. Cattle manure is the most important to the farmer. Horses' manure is dry as compared with that of cows and pigs, and is therefore rapidly heated and fermented; hence it is termed 'hot;' whilst cattle manure for the reverse properties is called 'cold.' This difference in the nature of the various manures is one of the main reasons why it is advisable to thoroughly mix them in the manure pit, or in making a manure heap. The composition of the manure will also depend upon the age and condition of the animal. Thus old animals and fattening animals make rich manure. Young calves and growing animals, cows in calf or yielding milk, animals having much work to perform, and lean animals, extract a larger quantity of nutritive matter from their food than old, fat, or resting animals, and consequently their manure is of less value.

Secondly, the food of the animal will materially influence the value of the manure. Thus the richer the food in phosphates and nitrogen the richer will be the manure, because the main portion of these two principal constituents of food is not absorbed by the animal. Consequently, the value of the excrement resulting from the consumption of a ton of grass, or a ton of hay, straw, turnips, grain, or cake, is very different, and depends upon the amount of phosphates and nitrogen originally present in these substances.

Sir John Lawes has endeavoured to estimate the value of this manure as produced by various substances, and Dr. Voelcker has made similar calculations. The following table gives the results of these calculations:—

Estimated Value of Manure from Consumption of One Ton of the following Articles of Food.

	Lawes	Voelcker
	£ s. d.	£ s. d.
Linseed cake .	4 12 6	3 15 8
Cotton cake	3 18 6	—
Decorticated cotton cake	6 10 0	5 6 6
Rape cake	4 18 6	4 0 9
Beans	3 14 0	3 2 0
Peas	3 2 6	3 2 0
Indian corn	1 11 0	1 5 0
Locust beans .	1 2 6	0 18 3
Malt dust	4 5 6	3 11 0
Malt	1 11 6	1 6 0
Barley	1 10 0	1 5 0
Oats	1 15 0	—
Wheat . .	1 13 0	1 7 0
Bran and pollard	2 18 0	2 15 0
Rice meal	—	0 15 0
Palm-nut meal	—	1 14 0
Brewers' grains	—	0 12 0
Hay (clover) .	2 5 6	—
Hay (meadow)	1 10 6	—
Straw	£1 to 10s.	—
Mangel wurzel	0 5 3	—
Swedish turnips	0 4 3	—

These figures are theoretical, and in practice, from one cause or another, it is found that the manure seldom comes up to this theoretical value.

Thirdly, the nature and the quantity of litter used will affect the value of the dung. No matter what may be the nature of the droppings, they will invariably be worth more, weight for weight, than the substanee used for litter; hence it is evident that the less the litter, the richer and more valuable will be the manure. The quantity of litter, however, should be regulated not in consideration of the manure, but of the condition of the animals, neither too much being used nor yet too little—sufficient merely for cleanliness and comfort. Wheat straw is for the most part used for litter, sometimes barley or oat straw. In stables, sawdust, and more recently German peat moss, have come greatly into use. Sawdust itself possesses no manurial value, but it does not, as is sometimes supposed, injure either the land or the crops. Both sawdust and peat moss absorb the droppings largely, and the resulting manures may be used with special advantage on clay soils. The value of sawdust manure depends entirely on the nature and quantity of the droppings which it has received, and its worth, therefore, can only be diseovered in each case by chemical analysis. The same is true to a great extent of German peat moss manure. Though the moss possesses itself slight manurial value, the value of the manure made from it depends mainly on the droppings it receives.

The chemical composition of farmyard manure formed one of Voelcker's earliest and most complete investigations. His figures, though undoubtedly ineomplete, may still be quoted as best illustrating the subjeet, for future seientific work has added little to them. The following table gives the composition of fresh and rotten farmyard manure, consisting of the mixed droppings of horses, cows, and pigs, and of the straw used as litter :—

Farmyard Manure (*Voelcker*).

	Fresh		Rotten	
Water . .		66·17		75·42
*Soluble organic matter . .		2·48		3·71
Soluble inorganic matter (ash) :				
Soluble silica	·237		·254	
Phosphate of lime .	·299		·382	
Lime .	·066		·117	
Magnesia .	·011		·047	
Potash	·573		·446	
Soda . . .	·051		·023	
Chloride of sodium	·030		·037	
Sulphuric acid	·055		·058	
Carbonic acid	·218		·106	
	——	1·54	——	1·47
†Insoluble organic matter .		25·76		12·82
Insoluble inorganic matter (ash):				
Soluble silica	·967		1·424	
Insoluble silica	·561		1·010	
Oxides of iron and alumina	·418		·673	
Phosphoric acid	·178		·274	
Phosphate of lime	(·386)		(·573)	
Lime .	1·120		1·667	
Magnesia	·143		·091	
Potash	·099		·045	
Soda .	·019		·038	
Sulphuric acid	·061		·063	
Carbonic acid .	·484		1·295	
	——	4·05	——	6·58
		100·00		100·00
*Containing nitrogen		·149		·297
Equal to ammonia		·181		·360
†Containing nitrogen		·494		·309
Equal to ammonia .		·599		·375
Ammonia in free state .		·034		·046
Ammonia in form of salts		·088		·057

These figures show that the amount of organic and inorganic matter soluble in water is small in the fresh manure when compared with that in the well-rotten dung. The insoluble organic matter is considerable in the fresh manure, but much less in the rotten manure. Correspondingly, the nitrogen in the fresh manure exists mainly in an insoluble form, whilst in the rotten manure there is far more soluble.

The principal inorganic constituent of the soluble part of farmyard manure is potash. This exists not as carbonate of potash, but as silicate, which accounts for the large amount of soluble silica present in dung. The principal mineral constituent of the insoluble ash is lime. It will be noticed that there is a considerable quantity of phosphate of lime in both the soluble and insoluble mineral matters.

The most striking peculiarity of farmyard manure is the great variety of substances it contains. Every one of the mineral constituents found in the ashes of plants is present in good farmyard manure. Thus it constitutes a universally serviceable manure, and well deserves, from its chemical composition alone, apart from the physical action which it exerts upon the soil, the high reputation it has obtained.

It will be seen that in the rotten dung the amount of soluble phosphate of lime has considerably increased, the other soluble constituents remaining approximately the same.

Farmyard manure is essentially a nitrogenous manure, for the nitrogen in it is relatively in far larger proportion than the other constituents. That it should be a nitrogenous manure will not be wondered at when it is considered that animals are computed to retain less than $\frac{1}{9}$ of the total nitrogen of their food.

The changes which take place in the dung heap during the rotting of dung are due to a species of fermentation. Whenever organic compounds, containing nitrogen, are exposed to air and moisture, their decomposition or putrefaction commences with the evolution of heat and gases, and the formation of new chemical compounds. It is easy to prove the production of heat in the fermenting of the dung heap by means of a thermometer, but the fact is well known to all. Of the gases which are eliminated, the most considerable proportion consists of carbonic acid. A little sulphur may be converted into sulphuretted hydrogen gas, and a little phosphorus into phosphoretted hydrogen gas, and these two strongly smelling gases give to the gases proceeding from the dung heap part of their smell. The most valuable substance liable to pass off is nitrogen. It does not escape in the form of ammonia, as most people think, but as carbonate of ammonia. It is in order to retain this carbonate of ammonia in the heap, and to keep the rain out, that it is advisable to cover with soil heaps of farmyard manure made in the field.

The substances formed by the partial decomposition or fermentation of farmyard manure are far more soluble than the substances contained in the fresh dung; hence the action of rotten dung upon the crops is more rapid than that of fresh dung. When fresh dung is applied to the soil, those changes will have to proceed in the earth which in the case of rotten dung have previously taken place in the manure heap.

Among the substances produced by the fermenting of dung, there are certain organic acids similar to those found in the soil, which were termed collectively humus. These have a strong affinity for ammonia, and hold it firmly in combination, and it is on this account that the loss of ammonia by the fermenting of dung is so small.

These humus acids also combine with potash, and the resulting compounds form a large proportion of, whilst they give the colour to, the drainings of dung heaps. These drainings should, therefore, on no account be lost, as is unfortunately so frequently the case, for they are rich in the very compounds which give to farmyard manure its special value. To show how valuable they are the following analyses may be quoted; the one being the analysis of the liquid passing from a recently put up heap of mixed farmyard manure, the other the analysis of the liquid running from a well-fermented heap. The results represent grains per gallon:—

Farmyard manure drainings (*Voelcker*).

	Fresh		Fermented	
Ammonia (combined with humic acids)		15·13		39·36
*Organic matter		716·81		356·30
*Containing nitrogen	31·08		3·59	
†Mineral matter		625·80		368·98
†Consisting of:—				
Soluble silica	9·51		1·50	
Phosphate of lime and iron	72·65		15·81	
Carbonate of lime	59·58		34·91	
Carbonate of magnesia	9·95		25·66	
Sulphate of lime	14·27		4·36	
Chloride of sodium	101·82		45·70	
Chloride of potassium	60·64		70·50	
Carbonate of potassium	297·38		170·54	
Total		1357·74		764·64

If the total quantity of solid matter in the drainings from the fermented heap is smaller than that in the drainings from the fresh heap, it contains as much nitrogen, and this nitrogen, instead of being in the form of organic compounds, as in the fresh manure, is now in the form of ammonia. There is also in these drainings a certain amount of nitrogen existing as nitric acid. Thus a study of the drainings of dung heaps gives another proof of the effect which fermentation has in rendering insoluble substances soluble. It also shows how the ammonia which is formed is prevented from escaping in the form of vapour, as is popularly but erroneously supposed, owing to its becoming combined with organic acids. It is only in the centre of the fermenting dung heap, where the temperature rises from about 130° to 150° F., that free ammonia, or carbonate of ammonia, exists, and before this can escape into the atmosphere it is condensed in the external and colder portion of the dung heap or combines with the acid humic substances. Hence it is only when dung heaps are turned that there can be any appreciable loss of ammonia, and it is owing to the loss which then necessarily takes place that it becomes impolitic to turn a dung heap more than once, if even it be necessary to turn it at all. The peculiar smell given off by dung heaps and most decomposing organic matters has not yet been thoroughly investigated, but probably it is accompanied by no perceptible loss in weight.

In undergoing decomposition farmyard manure suffers a loss in weight, does it also suffer a loss in fertilising properties? This question may be answered unhesitatingly in the affirmative, where the manure heap is allowed to lose the more soluble of its constituents by draining, or by their being washed out.

The loss sustained by farmyard manure on keeping amounts in round numbers to forty per cent. This is partly moisture, partly carbon and oxygen in the form of carbonic acid, and there is a minute loss of nitrogen.

If the farmyard manure loses forty per cent. of its weight in the process of fermentation, then 60 parts of the rotten dung should be of equal value to 100 parts of fresh dung. So far as the few analyses show this is not the case. That the rotten dung is richer than the fresh dung is true, but the increased percentage value does not make up for the loss in bulk. In fact there can be no doubt that, however carefully made and preserved, farmyard manure suffers loss in the fermentation which takes place when it is kept.

The application of farmyard manure.—It must be borne in mind that farmyard manure may be used either fresh or rotten. Fresh manure should be applied to stiff soils, such as clays; rotten manure to light soils. The stiff soil is improved in its physical character by the application of fresh, or 'long,' farmyard manure, inasmuch as it is made lighter and easier to work, while it retains the products of the decomposition of the manure. The light soil does not require to be made lighter, and it would not retain through the winter the valuable constituents of the manure, but would allow them to be washed into the drains; hence on light soils rotten manure is employed in the spring, at the time of year when plants are in most vigorous growth, and will rapidly absorb the nutriment the manure affords. It is found that, whilst the fresh dung loosens clay soils, the rotten dung consolidates light soils.

Farmyard manure, when applied to the land, greatly increases the water-holding capacity of the soil. The same indeed may be said of all manures containing a large quantity of organic matter, and this is one reason for the custom of ploughing a green crop into the soil as manure. Manures containing a large quantity of organic matters are consequently of great value on light sandy soils, and in hot, dry climates such as prevail in some of our colonies.

Farmyard manure, in one form or the other, is applied at all times of the year. For example, beans will be manured with fresh dung in the winter, grass seeds with rotten dung in the spring, turnips in the summer, and so forth.

Where the four-course system of cropping is pursued, of which hereafter, the swedes or roots which are taken the first year will be heavily manured with rotten dung in the summer. If there be a sufficient quantity of farmyard manure made on the farm to allow of the application of some to another crop, it is best used during the third year on the young clover seeds in the winter, or early spring.

Farmyard manure is seldom bought, the nearest approach to it being the stable manure of towns, but this can only be used with profit in close proximity to the towns, otherwise the cost of carriage is so great as to exceed the value of the manure. The quantity of manure made on the farm must therefore regulate the amount which may be used per acre. The quantity generally applied varies considerably, amounting often to 20 tons, or cart-loads, per acre. Ten tons an acre may be used with considerable advantage. From what has preceded, it is evident that to produce a given result a much larger quantity of fresh manure will be needed than of rotten.

The quantity of dung made on a farm depends upon the straw which is obtained from the corn crops, wheat and barley. On an average the straw from an acre of wheat or barley will weigh 1 ton to 1½ ton. A fatting animal will require for litter about 3 tons of straw in the year, and will make about 12 tons of manure, or each ton of straw is nearly equal to 4 tons of manure. A farmer, therefore, makes 8 tons of manure for every acre of that part of his land which on the four-course system is put down to turnips.

The number of cattle which can be supplied with litter from a given area of arable land, or, in other words, the number of acres which shall be kept in corn to find litter for a given number of cattle, is, of course, a matter of considerable importance to the practical farmer. It is impossible to lay down any hard and fast rule on this subject, for much will depend upon the way in which the animals are stored, and whether the object is to keep as few or as many cattle as possible. On an average, it may be assumed that each fattening beast will use 3 tons of straw for litter in the year ; hence it may be said that for every head of cattle there must be over two acres of corn crops, even where all the straw is used as litter.

If, therefore, a farmer has a larger number of live stock than this, so that they are not in proportion to the arable land, he must needs buy straw for litter, and then he will probably make more manure than his arable land needs, and so have to sell it. Buying straw and selling manure are practices of doubtful economy.

When rotten manure is applied to the land it should be ploughed in immediately after its application. Green or fresh manure, especially when applied in winter, may be left on the land a short time before being ploughed in without suffering loss. With some systems of farming this is both a convenient and practicable method of applying farmyard manure, and as it has been shown that the manure loses its value in some slight degree by keeping, there can be little doubt that this system is, at the same time, the most profitable.

The constituents extracted from the soil by the four crops grown in an ordinary rotation were given in a table in a preceding chapter. From this it will be seen that there is carried away of nitrogen, 296 lbs., potash, 226 lbs., and phosphoric acid, 90 lbs. The phosphoric acid is about one-third the quantity of nitrogen.

The analysis of farmyard manure shows that, roughly speaking, 1 ton contains 12 lbs. of nitrogen, 11 lbs. of potash, and 5 lbs. of phosphoric acid. It is evident that the relation is somewhat similar to that existing between the substances taken out of the soil by the crops, and consequently farmyard manure might be expected to prove a universal and complete manure. To a certain extent it does. But there is an important exception. When the swedes are eaten off by sheep on the land instead of being taken away, the amount of nitrogen returned to the soil will be five times as great as the quantity of phosphoric acid.

The same thing will occur, to some extent, if the clover hay be eaten by stock on the farm; the quantity of nitrogen returned to the soil becomes far greater relatively than the phosphoric acid. It is found in practice that soils so treated and manured with farmyard manure alone become over-stocked with nitrogen, and deficient in phosphoric acid. The result of this is either the too rapid growth of crops of a sickly character, liable to disease; or a waste of nitrogen. In practice, therefore, in addition to farmyard manure, it is necessary to occasionally use some manure which will give to the soil phosphate of lime.

Liquid manure.—It has been already shown that the drainings from the dung heap are of great value, and it was recommended that they should be collected. There will accumulate on the farm other liquid substances, partly from the yards and partly from the house, and to these collectively is given the name of *liquid manure.* Some time ago it was hoped that all the difficulties of manuring the soil would be solved by the aid and proper use of liquid manure. Farmers went to immense expense: firstly, to store this manure; and, secondly, to find means of distributing it over the ground like irrigation water; but the result was not a success, either in the crops or financially. In some cases it failed because the manure was too weak, in others because it was too strong, and moreover it supplied to the soil ammonia only where phosphates were mostly required. Whilst liquid manure permits of no large expenditure on its storage and utilisation, because it is of very slight value compared with artificial manures, yet it should never be wasted but collected in tanks, and utilised at as little expense as possible. Its composition varies so greatly according to whether it is more or less pure urine, or mixed with rain and other washings, that no analysis of liquid manure could be taken as at all representative. The great practical difficulty of the farmer is how to dispose of it profitably. If farmyard manure be well made, and kept in pits free from rain, it will be generally found somewhat too dry to ferment thoroughly, for fermentation requires a certain amount of moisture. No plan of utilising liquid manure is better than to apply it as required to the farmyard manure to supply this necessary moisture, and this method of utilising it will prove of special service where a large quantity of straw is used as litter. Much of the liquid manure may thus be disposed of; the remainder will rapidly ferment, and carbonate of ammonia and ammonia be formed. As these substances are more or less volatile, their loss must be prevented. It is usual, therefore, to add from time to time a little sulphuric acid to the liquid manure, to neutralise the ammonia as it is formed, and so fix it by converting it into sulphate of ammonia, which is not volatile. The neutralised liquid manure should be utilised, where possible, upon the land. It may be distributed by a liquid manure cart, which is similar to the carts used for watering the streets of towns. Only upon certain soils, however, can liquid manure be applied with advantage. Clay soils will not take liquid manure, but light sandy soils of good depth, with porous subsoils, are benefited by its application. It is upon these light sandy soils that the use of liquid manure has been attended with such considerable success upon the Continent. The reason why it is a mistake to use liquid manure upon heavy clay soils will be apparent when the physical properties of such soils are remembered. If the whole of the liquid manure cannot be employed upon the farmyard manure, and the remainder cannot be placed on the land, it is best to use sawdust to absorb it, and the manure thus formed will be of great benefit upon heavy clay soils, tending to lighten their texture, as well as increase their fertility.

Human excrements.—Closely allied to the utilisation of farmyard manure is the subject of the utilisation of human excrement. To anyone who has thought of the matter it may seem strange that, whilst the present generation of farmers spend immense sums of money in artificial manures, there was a time when these were unknown, and farming was not so bad even then. There can be little doubt that the necessity for artificial manures has greatly increased since the present method of disposing of human excrement in towns. In the past, what was taken off the land was in the main returned to it in the excrements. Now, the excrements of vast numbers of the population are washed away to the ocean.

The following analyses by Professor Way will illustrate the composition of solid and liquid human excrement:—

Human Excrements (*Way*).

	Solid	Liquid
Water	75·00	97·00
*Organic matter	22·13	2·02
Lime	·43	·02
Magnesia	·38	·01
Phosphoric acid	1·07	·04
Potash	·30	·05
Soda salts, &c.	·32	·86
Silica	·37	trace
	100·00	100·00
*Containing nitrogen	1·50	·58
Equal to ammonia	1·82	·71

The value of these substances is not great so far as their quality is concerned, but when the quantity is taken into account it becomes enormous. This has been seen by many, and numberless are the attempts which have been made to obtain these substances and return them to the soil. In the country, they find their way either into a brook or cesspool, the latter being emptied regularly, and the manure used upon the land. In towns, cesspools have been done away with and sewerage substituted. There are, however, one or two methods of treating the excrements so as to return them to the land. The best known is the earth-closet system, by which the excrement is treated with earth and ashes, the earth and ashes being used sometimes three or four times over. The final product is called earth-closet manure. The following is an analysis of such a manure where the earth had been used three times over:—

Earth-Closet Manure (Voelcker).

Moisture	13·81
*Organic matter	10·53
Oxides of iron and alumina	10·76
Phosphoric acid	·44
Carbonate of lime	1·84
Magnesia	·78
Alkaline salts	·64
Sand	61·20
	100·00
*Containing nitrogen	·44
Equal to ammonia	·53

The above analysis illustrates the very slight fertilising property of this manure, and the same is found to be the result with every method as yet devised of treating excrement. It is due partly to the fact that the urine is lost, and partly owing to the quantity of valueless substances with which the excrement has to be mixed. Upon comparison, this earth-closet manure will be found to possess only half the fertilising property of farmyard manure.

The inability to convert human excrements into valuable manure, because the valuable constituents pass off in the relatively large quantity of liquid manure, has caused all attempts to profitably utilise the sewage of towns to be hitherto futile; hence they have been discharged into the nearest river. This has caused the gradual pollution of our rivers, to prevent which many methods for the disposal of town sewage have been tried. It would be useless to mention these various methods in detail. Generally speaking, and as affects agriculturists, they may be divided into two classes: firstly, those which make out of the sewage mud a manure generally designated by the name of the town where made—such are the Manchester, Rochdale, Stafford, and other corporations' manures—these empty the partially purified liquid into the river; secondly, those which utilise the sewage for irrigation purposes. As no system has yet been discovered of taking out of solution the valuable portion of the sewage, viz. its nitrogen, consequently all sewage manures are of necessity poor manures, and seldom worth the price asked for them. Take as an example the following manure :—

Sewage Manure.

Moisture	13·60
*Organic matter	27·86
Phosphate of lime	2·79
Oxide of iron and alumina	19·62
Carbonate of lime	12·27
Insoluble silica	23·86
	100·00
*Containing nitrogen	1·53
Equal to ammonia	1·86

If we compare this with other manures, and with farmyard manure, we shall find it is not worth more than 2*l.* per ton, and probably few, if any, sewage manures are worth more, yet this price is much below what they are sold at.

Sewage irrigation.—Where the sewage is used for irrigating purposes, what are now termed sewage farms have sprung up.

Their first essential is a light porous soil capable of absorbing an immense amount of liquid. Secondly, the land must be constantly cultivated, so that in fact there shall always be a crop. In some cases grass is thus grown, and upon it cattle fed, to supply milk to the town. In many cases rye grass is the main crop, and five or even more crops of this grass may be taken off the land in one year. But the most recent and one of the best methods of utilising the sewage farm is in the cultivation of vegetables. These will vary according to local circumstances and demand. Many of the most flourishing market gardens around Paris are sewage farmed, and the same may be said of many market gardens in England.

CHAPTER XI.

ARTIFICIAL MANURES.

THE first and most natural manure employed by the farmer is farmyard manure. Relatively speaking, it supplies more nitrogen to the soil than phosphoric acid. Experience long ago taught farmers that it was advisable or beneficial to employ bones as a manure upon most soils, even when they had received farm-yard manure. Subsequent experience has only confirmed this knowledge, and at the present day, and probably for all future time, bones in one form or another are and will be the chief of all phosphatic manures. As it is advisable that these, and all manures, should be applied to the soil in as fine a condition as possible, bones are broken up before being sold to the farmer, and are sold according to the size to which they have been brought—as one-inch bones, half-inch bones, and quarter-inch bones or bone meal. Now a large outlay is made every year by a farmer in the purchase of artificial manures such as bones, and it seems probable that this item of expenditure is likely to increase rather than diminish with the further development of agriculture; hence it becomes of considerable importance to a farmer that he should obtain genuine substances. This can only be ensured by his knowing what the genuine article is, and where to look for adulteration. In treating of these artificial manures, analyses will therefore be given which have been made by myself and represent commercial articles. And each analysis will represent not a poor nor a middling sample of such manure, but a good sample, and one which it should be the aim of the farmer to equal.

The following, then, may be taken as representing the composition of pure bones of good quality :—

Bones.

Moisture	9·90
*Organic matter	33·70
Phosphate of lime	49·12
Alkaline salts, magnesia, &c.	6·18
Insoluble silicious matter	1·10
	100·00
*Containing nitrogen	3·76
Equal to ammonia	4·57

With one-inch or half-inch bones there is not much scope for adulteration, but, owing to the fine condition of bone meal, its adulteration is largely practised. This is most frequently done by adding gypsum or sulphate of lime to the bones, sometimes to the extent of over twenty per cent. In such cases the bone dust is unusually dry, and when being used flies into the men's faces and causes them considerable annoyance. It will be seen that pure bones contain about fifty per cent. of phosphate of lime, and nitrogen equal to four and a half per cent. of ammonia. The nitrogen exists as gelatine, and is only converted into ammonia by the slow decomposition of the gelatine in the soil. The phosphate of lime existing in bones is generally termed the tricalcic phosphate, represented by chemists as consisting of three portions of lime and one of phosphoric acid, or symbolically

$3\,CaO, P_2O_5$. This is not its exact composition; according to Hoppe-Seyler it is more correctly $9\,CaO, CaCO_3, 3\,P_2O_5$, and my own experiments confirm to some extent this view. It thus appears that intimately connected with the phosphate of lime there is also some carbonate of lime. These minutiæ, however, are of slight importance to the agriculturist; for all his purposes 'bone phosphate' is synonymous with the simple tricalcic phosphate, $3\,CaO, P_2O_5$. This substance is but slightly soluble in water, it consequently remains in the land, and is only slowly acted upon so as gradually to become available for plant food. The decomposition of the gelatine in the bones is more rapid, however, and produces substances which cause and are caused by fermentation. These substances dissolve in water, and the phosphate of lime is somewhat more soluble in this solution than in pure water. If, therefore, we take bones, slightly damp them, and allow them to stand in a heap, they will gradually rise in temperature, owing to the fermentation or decomposition of the gelatine, and after this has been allowed to proceed for some time we find the bone phosphate far more soluble in water than it was originally. Hence the gelatine in bones, apart from its great value as a manure, is also valuable from the increased solubility which its decomposition gives to the phosphate of lime. This gelatine is useful in the arts for the manufacture of glue, and large quantities of bones are annually used for its production The gelatine may be extracted from the bones by simply boiling, or by steaming them. The extracted bones are sold for manure as boiled or steamed bones, as the case may be. The following analyses illustrate the composition of a good sample of boiled bones :—

Boiled Bones.

Moisture	10·61
*Organic matter	21·55
Phosphate of lime	60·19
Carbonate of lime, magnesia, &c.	5·81
Insoluble silicious matter	1·84
	100·00
*Containing nitrogen	1·76
Equal to ammonia	2·13

The boiling has taken out as much organic matter as would have contained nearly two and a half per cent. of ammonia, whilst the phosphate of lime is only ten per cent. more than in bones. Often the ammonia is less than this, and the phosphate will sometimes amount to no more than that in bones. Consequently boiled bones are far less valuable than bones, though they are often sold as if they were 'bones,' and at a price for which bones might and ought to be bought. Being brittle and porous they can easily be distinguished from bones. The action of boiled bones in the soil would be slower than that of bones, owing to their containing less gelatine, but more rapid owing to the much finer state of division to which it is possible and usual to reduce them. Probably, taking both points into consideration, they act with about equal rapidity.

One other substance produced from bones is used as manure, though to a far larger extent by the manufacturer of artificial manures than by the farmer; it is bone ash. This is the ash of bones which have been burnt, and it is largely imported into England from South America. Bone ash varies greatly in quality, containing from sixty to eighty per cent. of phosphate of lime, which is the only substance of value in it.

Probably the first truly artificial manure introduced into England was Peruvian guano. Even this was within the last half century. Guano is the excrement of birds, which has accumulated in vast quantities. There are two classes of guano: those deposited in climates where there is little or no rainfall, of which the Peruvian guano is the best illustration; and those deposited where rain falls and washes out the soluble and nitrogenous substances, leaving the less soluble and phosphatic matter. These latter are called phosphatic guanos.

Peruvian guano when first imported into England was exceedingly rich in nitrogenous compounds, consisting partly of ammonia salts, and partly of organic matter containing nitrogen. In 1864 Voelcker published a paper, in which he gave the composition of guano as it was then being imported into England. By the side of this compare an analysis which shows the composition of what would now be called a good guano.

Peruvian Guano.

	1864, Voelcker	1882
Moisture	18·42	8·45
*Organic matter and salts of ammonia . .	52·11	43·15
Phosphate of lime	21·99	23·45
†Alkaline salts	6·37	16·30
Insoluble silicious matter	1·11	8·65
	100·00	100·00
*Containing nitrogen	15·34	10·20
Equal to ammonia .	18·62	12·39
†Containing phosphoric acid	2·23	5·52
Equal to phosphate of lime	4·83	12·04

This shows how great has been the falling off in the quality of guano; even the example here given is exceptionally good, and it is now far more frequent to find in guano nitrogen only equal to nine per cent. of ammonia. The phosphates have somewhat increased, but the greatest change is in the insoluble silicious matter, which now occasionally amounts to twenty or thirty per cent. The fact is, the deposits are getting exhausted, and the time cannot be far distant when there will be no more guano. Guano being the excrement of birds, is, perhaps, of all manures the nearest approach to a general manure like farmyard manure; it is of course far more concentrated. In addition to the nitrogen and phosphoric acid which it contains, guano also has about two per cent. of potash. Some guanos contain small quantities of nitric acid. Guano has been found universally applicable as a manure, it can be used on all soils and for all crops alike with advantage. Its scarcity, however, and consequent high price, is rapidly limiting its use as a general manure, and it is now mostly employed as a top-dressing in spring upon the winter-sown wheat, or is applied with the spring-sown barley. In either case, 2 cwt. per acre will be ample to use.

Bones and guano contain not merely phosphoric acid, lime, and nitrogen, but also small quantities of potash, and they may be looked upon as more or less general manures.

There is one other substance employed as a manure which may also be termed a general manure, it consists of dried fish refuse; the best is imported from Norway. It is known by several names, such as fish guano, marine guano, &c. Upon light soils it may be used with advantage. The following represents a sample of average composition :—

Dried Fish Refuse.

Moisture	12·70
*Organic matter .	59·65
Phosphate of lime	18·60
Alkaline salts	5·50
Insoluble silicious matter	3·55
	100·00

*Containing nitrogen	7·50
Equal to ammonia	9·11

It has been shown that nitrogen, phosphoric acid, and potash are the three substances most required by plants which are taken from the soil; that these three exist in the soil in only small quantities, so that the plant has some difficulty in obtaining sufficient quantity for its mature growth. These substances, nitrogen, phosphoric acid, and potash, consequently form the main constituents of all manures. Manures containing all three in appreciable quantities are termed general manures, being generally applicable. Farmyard manure is the type of such manures. Then come bones, guano, and fish, all of which have been described in detail.

The remaining substances used as manure are of a less general and more special character, and contain for the main part one only of these three primary constituents. Those manures containing phosphoric acid will be first described. They are termed phosphatic manures, and are the most numerous. As it requires a certain amount of chemical knowledge to realise their peculiarities, they are somewhat difficult to understand. It is of importance, however, that the farmer should understand and have a very clear idea of the nature and properties of these phosphatic compounds.

Dissolved manures.—It has been previously mentioned that the phosphate of lime contained in bones—that is, the tricalcic phosphate—is only slightly soluble in water. It is possible, by chemical processes, so to change this tricalcic phosphate as to render it easily and completely soluble in water. From the tricalcic phosphate—which contains three parts of lime—either one part of lime or two parts of lime can be taken away, and water put in the place of the lime which has been removed. This change can be best illustrated by a chemical diagram. If we represent lime by the symbol CaO, water by the symbol H_2O, and phosphoric acid by the symbol P_2O_5, the following diagram will illustrate what takes place in making the changes just referred to:—

$$\left.\begin{matrix} CaO \\ CaO \\ CaO \end{matrix}\right\} P_2O_5 \qquad \left.\begin{matrix} CaO \\ CaO \\ H_2O \end{matrix}\right\} P_2O_5 \qquad \left.\begin{matrix} CaO \\ H_2O \\ H_2O \end{matrix}\right\} P_2O_5$$

The first phosphate, having three parts of lime, is termed tricalcic; the second dicalcic, because it has only two; and the third monocalcic, representing one part of lime. This monocalcic phosphate is most soluble in water, and is therefore known as soluble phosphate. It appeared to Liebig that this soluble phosphate would be far more beneficial to plants than the insoluble tricalcic phosphate. He therefore suggested that manures should be made containing this substance, and pointed out that it was capable of being done by mixing the tricalcic phosphate or the bones with sulphuric acid. Sulphuric acid is represented chemically by the symbol H_2O, SO_3, and the change which takes place may be easily understood by the following diagram :—

$$\left.\begin{matrix}CaO\\CaO\\CaO\end{matrix}\right\}P_2O_5 \text{ and } \begin{matrix}H_2O, SO_3\\H_2O, SO_3\end{matrix} \text{ become } \left.\begin{matrix}CaO\\H_2O\\H_2O\end{matrix}\right\}P_2O_5 \text{ and } \begin{matrix}CaO, SO_3\\CaO, SO_3\end{matrix}$$

One part of phosphate of lime is mixed with two parts of sulphuric acid. Each part of sulphuric acid takes one equivalent of lime (CaO) from the phosphate, and gives to it water (H_2O) instead.

Thus monocalcic phosphate is formed, and also two parts of the substance CaO, SO_3, which is sulphate of lime, or gypsum. The pure sulphuric acid, however (H_2O, SO_3), cannot be used in the manufacture of this substance, but has to be diluted with water. As the resulting manure must be a dry powder, or at least sufficiently dry to be brought to a coarse granulated powder, like so-called citrate of magnesia, great care has to be taken that only the proper strength and the proper quantity of sulphuric acid is used. Great heat is evolved by the chemical change which takes place on adding the acid to the bones, and this drives off a large amount of the water as steam ; subsequently the gypsum which is formed, by exerting its well-known property of absorbing moisture, causes the manure to become sufficiently dry for it to be pulverised. The resulting manure was called a *superphosphate*, and contained twenty per cent. of phosphate of lime, which had been made soluble in water. A curious fact must here be explained. Farmers in those days knew little of chemistry, and it would have been useless to tell them how much of this soluble monocalcic phosphate was present in a manure; they would not have understood it. They did know, however, what bone phosphate was, and so it arose that, instead of stating the quantity of this monocalcic phosphate, the quantity of bone phosphate which had been used to make this soluble phosphate, or the quantity rendered soluble, was given, and this soon obtained for itself the misnomer of 'soluble sulphate'; it retains that misnomer to this present day. Hence the term 'soluble phosphate' represents the bone earth, or tricalcic phosphate, which has been rendered soluble by acid, and not the real amount of monocalcic phosphate. The analyses to be soon quoted will further explain these terms. Liebig's original suggestion was made regarding bones only; subsequently it was discovered that mineral phosphates of lime could be treated in the same way, with exactly similar results, and in process of time there have arisen many manures so made; hence it is preferable to call all manures so treated dissolved manures.

Dissolved bones.—These will vary greatly with the nature of the bones they are made from. The total amount of phosphates will be from thirty per cent. to forty per cent. or more, and the nitrogen from one and a half to four per cent. The following represents the composition of an average sample:—

Dissolved Bones.

Moisture	12·01
*Organic matter and water of combination	31·39
Monocalcic phosphate	11·01
Equal to tricalcic phosphate rendered soluble by acid (soluble phosphate)	(17·25)
Insoluble phosphates	15·86
Calcium sulphate (gypsum), &c.	23·62
Insoluble silicious matter	6·11
	100·00
*Containing nitrogen	1·86
Equal to ammonia	2·26

The insoluble phosphates in genuine dissolved bones consist entirely of phosphate of lime. Dissolved bones are of all dissolved manures the most valuable, excepting, perhaps, so-called dissolved guano. They are profitably applied not only to benefit the succeeding crop, but to improve the land generally.

When boiled bones are dissolved the resulting manure, which is sure to be called dissolved bones, will contain far less nitrogen and slightly more soluble phosphate than genuine dissolved bones, while when bone ash is dissolved the resulting manure will contain no nitrogen, but should contain at least thirty to thirty-five per cent. of soluble phosphate. Its value will depend entirely upon this soluble phosphate, and it will therefore be used as if it were a dissolved mineral phosphate.

Some years ago this method of dissolving manures was applied to guano, or, more properly speaking, sulphuric acid was added to guano. The result was undoubtedly beneficial. It will be remembered that guano contains nitrogen in the form of volatile carbonate of ammonia. This carbonate of ammonia is, by the addition of sulphuric acid, converted into the non-volatile sulphate of ammonia and so fixed; hence guano which has been treated with sulphuric acid is often spoken of as ammonia-fixed guano, and this is really a more correct term than dissolved guano. Probably a very small portion only of the phosphate of lime is rendered more soluble. What is also of no small advantage is, that the manufacturer has the trouble of reducing the guano to a fine powder.

Superphosphate.—Liebig's original idea was to dissolve bones, but when it was discovered that the same chemical changes took place even if the substance acted upon were a ground crystal, or rock of phosphate of lime, then every substance containing phosphate of lime in anything like sufficient quantity became utilised in this way. The resulting manures, unlike dissolved bones, contained no nitrogen; and these manures are according to the true meaning of the word superphosphates. Before describing them it will be well to mention some of the principal substances used in their manufacture; these are termed

Phosphatic minerals.—Firstly come the coprolites. These are phosphatic nodules found in various parts of England—Suffolk, Bedfordshire, Cambridge, &c.—and supposed to consist mainly of the fossilised excrements and bones of extinct mammals. They contain about forty-five to fifty per cent. of phosphate of lime, as well as carbonate of lime, oxide of iron, sulphide of iron, and sand. This is also the general composition of all phosphatic minerals.

Small and isolated geological formations and deposits of phosphate of lime are found throughout the world. Some are supposed to be the result of a solution of phosphate of lime having found its way into a cavity of the rocks, and there concentrated; hence these are generally found in what are termed by geologists 'pockets.' When the deposit is crystalline it is known as 'apatite,' and when non-crystalline as 'phosphorite.'

These deposits are found in America, Norway, Germany, Spain, &c., and the mineral is generally named after the country, district, or place from which it comes, *e.g.* Norwegian apatite, Spanish phosphorite, Carolina phosphate, &c. The rock or mineral phosphates are seldom used by farmers until they have been converted into superphosphate. Apatite is less soluble than phosphorite. The value of these substances depends entirely on their contents of phosphate of lime. The mean of many analyses shows that the rock phosphates yield the following quantities of phosphate of lime:—Canadian, seventy-seven per cent.; French, seventy-five per cent.; Sombrero, seventy-three per cent.; Curaçao Island, seventy per cent.; Navassa Island, sixty-nine per cent.; Spanish, sixty-eight per cent.; Carolina, fifty-seven per cent.; Charleston, fifty-three per cent.

The phosphatic guanos, the formation of which has been previously described, are used like the mineral phosphates for the manufacture of superphosphate. Maldon Island guano and Mejillones guano may be taken as types.

Phosphatic Guanos.

	Maldon Island	Mejillones
Moisture	4·55	14·32 (Moisture and Organic matter together)
Organic matter	5·85	
Phosphate of lime	74·46	72·54
Carbonate of lime, alkaline salts, &c.	15·04	6·16
Silica	·10	6·98
	100·00	100·00

All these substances are utilised for the manufacture of mineral superphosphate, and the resulting superphosphate will contain from twenty to thirty per cent. of soluble phosphate, according to the method and materials of manufacture. The farmer in buying the manure should purchase it at so much for every per cent. of soluble phosphate, or what is known as so much per unit. At the present day it is possible to get good superphosphate at 2*s.* 6*d.* per unit, so that a ton of superphosphate containing twenty-four per cent. of soluble phosphate costs 3*l.*

A good superphosphate will contain little or no mineral still unacted upon by the acid, and hence remaining insoluble, and to the farmer the so-called insoluble phosphates in a superphosphate are practically worthless. This fact is now recognised by the manufacturers, and hence the custom of selling according to the soluble phosphate alone. The object of the manufacturer is, therefore, to bring every particle of the phosphate into a soluble condition. This is most easily done by using an excess of sulphuric acid; but then the resulting superphosphate is very acid, it does not properly dry, is not a good manure, and would prove injurious on soils deficient in lime. Hence, while buying superphosphates according to the quantity of soluble phosphate they contain, it is necessary to also stipulate and see that they are in a good condition—in other words, that they are dry and in a fine state of division, so that they can be put upon the land easily and uniformly.

The following may be taken as a typical analysis of a good mineral superphosphate:—

Superphosphate.

Moisture	18·92
Organic matter and water of combination	6·21
Monocalcic phosphate	15·66
Equal to tricalcic phosphate (rendered soluble)	(24·52)
Insoluble phosphates	5·14
Gypsum, &c.	48·23
Silica	5·84
	100·00

The use of superphosphate has been for the most part to land prior to the growth of swedes or roots, the quantity employed being from 3 to 4 cwt. per acre. The effect has been most striking, and the crops have risen from 14 tons to 20 tons per acre. Its further use will be stated hereafter.

Retrograde phosphates.—It has been observed that some superphosphates, which when first made contained twenty per cent. of soluble phosphate, after keeping some time contain only eighteen, or even less. This occurred more frequently abroad than in England, and has been shown to be due to the presence of iron in the mineral dissolved. The iron is converted by the sulphuric acid into sulphate of iron, which reacts upon the soluble monocalcic phosphate and converts it into a phosphate of iron comparatively insoluble in water. The phosphate, which had thus been rendered insoluble because it had gone back to its original insoluble condition, obtained the name of retrograde phosphate. Until quite recently this phosphate was not much recognised, but as the presence of these phosphates in many manures has been conclusively proved, the subject is receiving attention.

Precipitated phosphate is closely allied to retrograde phosphate. This substance is made by adding lime to a solution of soluble phosphate, and consists of a mixture of the dicalcic phosphate and tricalcic phosphate in proportions varying according to the method of manufacture. It has been found a valuable manure. The tricalcic phosphate, formed by this precipitation, is far more soluble than the tricalcic phosphate of a natural mineral phosphate, no matter how finely this latter may be ground.

Now, what becomes of soluble phosphate when it is washed into the ground? That it does not remain soluble is evident, for it does not pass into the drainage waters; hence, no sooner does it come into contact with the soil than it becomes fixed. This fixture may be produced by two substances, either by iron or by lime. It is therefore probable that the phosphates occurring in the soil after the application of superphosphate are either the same as retrograde phosphates, or as precipitated phosphate. The inability to comprehend these changes and the supposition that soluble phosphate becomes converted in the soil into the same kind of phosphate as is present in a mineral phosphate, have led many to assume that ground mineral phosphate was as valuable as soluble phosphate. Much money and time have been spent in a futile endeavour to prove this to be so, but of course the experiments have failed. Ignorance, however, is only slowly overcome, and, as from time to time the question of the relative merits of soluble and insoluble phosphates is debated, it will be well to remember these few facts. Firstly, the substances formed in the soil are not the same as those existing in the natural undissolved mineral, and are far more soluble. Secondly, it is evident that, no matter how finely a substance may be divided by machinery, it cannot subsequently be so thoroughly incorporated with the soil as it would become if in a soluble state, washed in by the rain and precipitated by the particles of earth as it came into contact with them. Lastly, there is no doubt that the state of division of the particles thus precipitated is infinitely finer than can be obtained by any grinding machinery extant. However great the difference between the relative value of soluble and insoluble phosphate may be, yet it must be clearly understood that finely ground phosphatic materials act as manure, and are of great value where soluble phosphate is not to be obtained or is not suitable.

There is a mineral phosphate, Rodunda Island phosphate, which, unlike those already mentioned, consists of phosphate of alumina and contains no lime; its composition being:—

Rodunda Phosphate.

Moisture, water of combination, &c.	24·20
Phosphoric acid	38·52
Iron and alumina	35·33
Sand	1·95
	100·00

It cannot be treated with sulphuric acid owing to the absence of lime, and consequent inability to dry it after treatment due to the non-formation of gypsum. Finely ground Rodunda phosphate has proved a good manure.

Whether combined with lime, iron, or alumina, phosphoric acid becomes available for the plant, and there is no conclusive evidence to show that the plant cannot assimilate phosphoric acid from all these combinations with equal ease.

Nitrogenous manures.—Of the many constituents of plant food no one appears to exert a greater influence on plant growth than nitrogen. Hence it forms one of the most, if not the most, important constituent of manures. It is invariably the most expensive. Nitrogen is a constituent of all vegetable and animal matter, being found in greatest quantity in the latter; hence every waste substance containing nitrogen has been pressed into the service of the manure dealer or manufacturer.

These nitrogenous substances, or manures, may be classified according to the manner in which the nitrogen they contain exists. Nitrogen may exist, first, combined with oxygen to form an acid—nitric acid—which acid will be combined with a base, such as soda or ammonia; or it may exist as ammonia, in which case the nitrogen is combined with hydrogen, and the ammonia forms the base of a compound or salt; or it may exist in an organic compound, in one of many forms of more or less complexity. Whatever form it may possess when applied to the soil, there is reason to believe that it is invariably converted into nitric acid before it can be utilised by the plant.

Nitrate of soda, the only available manure in which nitrogen exists as nitric acid is universally recognised as the most valuable nitrogenous manure. This salt is found in Peru and other places, and should contain, as sold, ninety-five per cent. of pure nitrate of soda. It is a frequent occurrence to find nitrate of soda greatly adulterated either with common salt, with sulphate of soda, or with both. Nitrate of potash is another salt containing nitrogen as nitric acid, but the price this substance fetches for the manufacture of gunpowder precludes its use as a manure.

Of the salts of ammonia, the one most frequently employed for manuring is the sulphate. Sulphate of ammonia is obtained in the purification of coal gas, and is sold as a crystalline powder; as a rule the freer it is from colour the better. When highly coloured it is liable to contain a substance injurious to plants. A good sample of sulphate of ammonia should contain from twenty to twenty-one per cent. of nitrogen, which is equal to twenty-four or twenty-five per cent. of ammonia. Pure nitrate of soda will contain only from fifteen to sixteen per cent. of nitrogen; so that, as a source of nitrogen, it must be used in larger quantities than sulphate of ammonia. Hence, if the price of nitrate of soda be more than three-fourths that of sulphate of ammonia, it is too dear. Sulphate of ammonia and nitrate of soda are both exceedingly soluble in water, and owing to the rapidity with which they are washed out of the soil must be employed only as top-dressings for application in the spring.

Substances containing nitrogen as organic matter may be of vegetable origin, such as rape cake, damaged oil cakes, shoddy, and soot; or of animal origin, such as dried blood, wool waste, skins, hair, and horn.

Of the many organic compounds existing in these substances and yielding nitrogen, only two need be mentioned.

Urea is an easily decomposable substance, which splits up into salts of ammonia. Nitrogen exists in this form in all liquid, and probably in some solid excrements, and it constitutes the main portion of the nitrogenous matter in guano, farmyard manure, &c. A nitrogenous substance similar to albumen, or white of egg, exists in all animal and most vegetable compounds. The nitrogen of dried blood, fish, animal products generally, *e.g.* wool waste, &c., exists mainly in this form. It is not easily decomposed, and the nitrogen which it contains only becomes available to the plant slowly; hence such manures are less valuable than those containing more readily available nitrogen. Their value depends solely upon the nitrogen they contain, and they should be bought accordingly, for this is liable to immense fluctuations. Thus, pure dried blood will contain seventeen per cent. of ammonia, while some samples will contain less than half that quantity. Wool wastes sometimes contain as much as ten per cent. of ammonia; shoddies six or seven. Shoddy is frequently impregnated with oil; it is then only very slowly decomposed in the soil, and is worth far less than when free from oil. Wool and shoddy are valuable for hops. Soot varies greatly in the quantity of nitrogen it contains, commencing at two per cent. and going up to as much as six per cent. The fact is that soot is frequently mixed with flue dust, which deteriorates it, and, while making it much heavier, greatly diminishes the percentage of nitrogen. Soot is a favourite manure to apply to grass land and to wheat, and, if good, is undoubtedly followed by beneficial results. Leather is sometimes employed to give nitrogen to the soil. If the leather be untanned it is valuable, but if tanned, useless, for it will then remain in the soil unacted upon, and not yield up its nitrogen.

The value of nitrogen depends upon the form in which it exists, and whilst it fetches from 16*s.* to 18*s.* a unit when present in the form of salts of ammonia, or, as in guano and bones, of easily decomposable organic substances, it is not worth more than 10*s.* to 12*s.* a unit when present in such substances as shoddy, &c.

Rape cake when too poor for feeding purposes is frequently employed as a manure chiefly for the nitrogen it contains. It has its advantages and disadvantages; unfortunately it frequently contains great numbers of weed seeds not sufficiently damaged to prevent their taking root and springing up in the soil. It is, however, a valuable nitrogenous manure, and besides nitrogen, equal to about five or six per cent. of ammonia, it contains small quantities of phosphate of lime and of potash.

The custom of ploughing in a green crop for manure has been already mentioned. Of the crops most suitable for this purpose the leguminous plants take precedence. Mustard is frequently grown to be ploughed in, more especially on land liable to wireworm, which pest it is said to kill. This and all such crops should be ploughed in just before flowering, so as to prevent the seeds coming into the ground. Even where a green crop is raised and not ploughed in there will be a large quantity of green matter which is not utilised. This should be collected and made into a compost, as is subsequently described.

Sea-weed is closely allied to green manure, and is highly esteemed as a manure wherever it can be obtained without much labour. Experience shows that it is of most benefit to the potato and clover crops, and there can be little doubt that this is mainly due to the potash which sea-weed contains in some small quantity. It also supplies a large amount of organic matter, thus improving the soil mechanically as well as enriching it with a little ammonia. These are also the reasons why green manuring is so beneficial. The reason of the valuable property of a clover stubble ploughed in as a preparation for the wheat crop is the same, viz. that it improves the condition of the soil and also yields up a large quantity of nitrogen. It is probable that much of this nitrogen has been brought up from the subsoil by the long roots of the clover plant, and this accounts for the extraordinary accumulation of nitrogen in the soil after the growth of clover.

It may be well to draw attention to the peculiar character of nitrogenous manures, such as guano, sulphate of ammonia, and nitrate of soda. Apart from supplying the ground with that most essential constituent nitrogen, these substances appear to exert a powerful stimulus upon the growth of the plant; hence they have been likened to foods which were also stimulants. The word stimulant is not altogether a misnomer as applied to nitrogenous manures, and helps to elucidate the facts which are associated with the use of nitrate of soda, &c. Like all stimulants they may do good, or they may do harm. Firstly as to the beneficial effects of nitrate of soda. It promotes a rapid growth. Now, if the food necessary for this growth be in the soil, close to the roots of the plant, the growth will be natural, and strong, and healthy, and the plant thus reaching maturity early will rapidly pass over that period in its growth when it, like all things we are acquainted with, seems most liable to disease, viz. the early stages. Thus we find, for example, that upon ground well manured and containing a sufficiency of plant food, a dressing of nitrogenous manure, like nitrate of soda, will induce in Swedish turnips such a rapid growth as to enable them to outstrip the ravages of their worst enemy, the turnip fly.

But if the soil be not in good condition, rich with plant food, and well manured with phosphates, then nitrogenous manures, such as nitrate of soda, have an injurious effect. They will force the plants unnaturally, without giving them that substance which makes them healthy and strong; and, instead of a plant capable of resisting disease, we obtain one peculiarly susceptible to it. Among many such diseases the blight on wheat and the potato disease may be mentioned. Cereals, especially wheat and barley, are also liable to 'lodge' or lie flat, which may be counteracted by applying salt, but the necessity to do this presupposes bad management. Even if such forced plants reach maturity, having mastered the attacks of disease, they will not be so nutritious, weight for weight, as those which have received sufficient manure; for though the total weight of a crop may be augmented, yet this is mainly due to such plants containing an excess of water, so that the total weight of nutriment in the larger crop may be less than that in a far smaller crop obtained from well-manured land. These remarks apply especially to root crops, such as swedes and mangels. The immense roots which are exhibited at agricultural shows are obtained by such forcing means, and do not at all represent what the farmer is able to obtain, nor indeed would it be advisable to obtain them, for they are less nutritious than the smaller and more ordinary roots, and they do not keep. To these peculiarities of nitrogenous manures are due the disputes which arise from the results of experiments, where nitrate of soda, or a similar rich nitrogenous manure, has been used. If the experiments be conducted upon good rich soil, then the results with nitrogenous manures are excellent. If the experiments be conducted upon poor, semi-exhausted land, then the result of the nitrogenous manure is a failure. Hence the experiments depend upon the soil and the climate where they were performed. This shows the fallacy of drawing universal truths from isolated results.

It may be mentioned that upon some soils one nitrogenous manure acts best, upon other soils a different manure. Thus nitrate of soda will be used with most advantage upon loams or light soils, ammonia salts upon heavy land; but this rule will have exceptions. If a soil be liable to damp, difficult to drain, and naturally very cold, nitrate of soda will not suit it; some such soils are found in Wiltshire, for instance.

Potash manures are of great value upon light land, and hence are much sought after. It is only within a comparatively recent period that any substance containing potash, and sufficiently cheap to enable it to be used as a manure, has been known. This was due to the discovery at Stasfurt in Germany of deposits of a salt termed kainit, which contains about twenty-five per cent. of sulphate of potash, mixed with common salt and magnesia sulphate. Potassium chloride, or, as it is commonly called, muriate of potash, is sometimes used as a manure; it contains more than double the quantity of potash contained in kainit, is consequently far more expensive, and must be used in less quantity. Two hundredweight of kainit per acre is a good dressing of potash, and will last for several years. It is needless to apply it to strong or clay land.

Soda salts.—Analyses of plants invariably show that they contain potash in far greater quantity than soda, and all experimental attempts to make soda take the place of potash have failed. It would seem, then, that soda salts—excepting of course nitrate of soda, which is employed for its nitric acid—are useless as manure. Experience, however, proves that this is not so, and that the application of soda salts, especially common salt, is attended with benefit to some crops. Thus, experience found that upon light soils which had been highly manured with a nitrogenous manure, such as farmyard manure, the application of soda salts generally produced a good result. Voelcker has shown that this is due to the action of the salt upon the substances present in the soil. The salt liberates ammonia, in the soluble form of chloride of ammonia, from insoluble organic compounds which are present in the soil, the acids of these compounds now combining with the soda, and so liberating the ammonia. It is owing to its chemical action in this way that salt when applied in conjunction with Peruvian guano produces such good effects. Some few plants, however, are benefited by common salt, because it enters largely into their composition; such is the mangel, to which it is often applied as a top-dressing, mixed in equal proportions with nitrate of soda.

Magnesia.—Sulphate of magnesia is sometimes used as a manure, usually in conjunction with other manures. Most plants contain small quantities of magnesia, and it is a disputed point as to how far magnesia is necessary or even useful as a manure. There is certainly no evidence at present to show that magnesia is necessary for plants, or that there is not in all fertile soils a sufficiency of this substance.

Usually, wherever there is a sufficiency of lime there is also a sufficiency of magnesia.

Special manures are formed by a mixture of the preceding substances. Such manures are generally sold by some specific name, according to the crop they are supposed to best suit. And thus we find most manure dealers selling their own special turnip, mangel, wheat, barley, and grass manures, &c. Some of these manures are good, some bad, nearly all are too expensive; and the agriculturist will find it far better to buy the ingredients and mix them for himself according to the requirements of his land and his crops, than pay ten shillings a ton, which is the least that the manure merchant will charge for mixing them, and giving them a special name. It may be said, how is the farmer to know what substances to buy, and in what proportion he should mix them. This information he can easily obtain from some well-qualified agricultural chemist—if not through his agricultural society or farmers' club.

Special manures are seldom anything more than mineral superphosphates, of too poor a quality to sell as such, and to which a little dried blood, shoddy, horn shaving, or some such nitrogenous substance has been added. Often such a manure, containing only seventeen per cent. of soluble phosphate, and ·5 per cent. of ammonia, is sold for 6*l.* per ton, while by buying a good superphosphate, containing twenty-five per cent. of soluble phosphate at 3*l.* 10*s.*, and dried blood containing nine per cent. of ammonia, at 9*l.* a ton, a mixture equal to the above manure can be made at a cost of 4*l.* a ton. In other cases a special manure is spoken of in the highest terms as containing some peculiar property, rendering it far superior to all other manures of the kind. If specially recommended for light soils, it will probably prove upon analysis to contain three or four per cent. of sulphate of potash, corresponding to about ten per cent. of kainit, costing at the most some 8*s*. to 10*s*.; the remainder will be a poor superphosphate with a little shoddy. Or, again, if the manure be specially recommended as a turnip manure, it will frequently contain some two or three per cent. of nitrate of soda added to dissolved bones; at the most this should not increase the price of the manure by 1*l*. a ton, whereas it is generally raised 3*l*. or 4*l*. a ton.

Finally, it is essential to be on one's guard against substances sold as 'manure,' 'artificial manure,' 'general manure,' and such terms; they are frequently almost worthless. The following analyses are examples of what may be expected in many cases, and illustrate how easy it is to waste money in the purchase of those substances over which, more than over anything else, the farmer has control if he will but expend a little time, a little trouble, and a little money.

Analyses of two worthless Manures.

Moisture	17·40	48·90
Organic matter	29·85	28·51
Oxides of iron and alumina	4·86	2·60
Phosphate of lime	2·51	1·79
Carbonate of lime	2·82	14·49
Alkaline salts and magnesia	6·41	1·47
Sand	36·15	2·24
	100·00	100·00
Containing nitrogen	1·71	·76
Equal to ammonia	2·07	·92

The first of these manures would be very dear at 2*l.* a ton, the second at 1*l.*

These figures should be sufficient to guard one in the selection of manures and to prevent wasting money upon them. It is easy to comprehend why some farmers are so prejudiced against artificial manures. The fact is, they have spent their money carelessly, have been deceived, and the crops have been in no wise benefited. It is not the fault of artificial manures if they do not repay the money laid out on them, but the fault is on the side of the farmer who spends his money carelessly.

CHAPTER XII.

THE PROFITABLE APPLICATION OF MANURES.

Having shown the nature of the various substances used by the farmer for manure, it will be necessary now to consider how they may be profitably employed, and what principles should be observed in their selection and use. The quantity of matter which has been written upon this subject is immense, owing to the diversity of opinions which exist upon the questions for consideration. The field experiments which have been conducted in England and abroad, more especially on the Continent, would take many volumes to describe, and it is only slowly that the truths which they teach can be discerned. To attempt to give in a chapter or two a *résumé* of this matter would be futile. It must suffice, therefore, to draw attention to some of the guiding principles which have been deduced, and to endeavour to show their practical as well as scientific value.

The object of the farmer in applying manure to his land will be either: (1) To improve the condition of the soil generally; or (2) to improve the condition of a certain crop or crops. It has already been laid down as an axiom that profitable farming necessitates the maintenance of the land in an increasing rather than decreasing state of fertility; yet, on the other hand, to apply manure to a soil which does not require it, or to use excess of manure, which is practically the same thing, is waste of money.

The excessive application of manure is often more than unnecessary expenditure. It is liable to produce an unnatural growth in the crops. Such growth is peculiarly liable to disease, and the loss of the whole crop may be the consequence; hence excessive manuring may, and often does prove, a double loss to the farmer of both manure and crop.

The foundation of the profitable use of manures is a knowledge of the exact composition of the soil, and every farmer should possess this knowledge of his farm. He will then know what is required to bring his land up to a normal condition of fertility. Soils in such condition are said by farmers to be in 'good heart.'

The information which a complete analysis of a soil affords will be of use for many years, and enable all questions as to manuring to be placed upon a reliable basis, especially if an account be kept of the manures used from year to year, and the crops taken off the land. It will save much expenditure, such as is frequently made upon needless manures, and will indicate how, by careful and limited manuring, far larger crops may be grown than would probably be grown without such information. The following facts afford striking proof of the value of an analysis of his soil to the farmer. The turnip crop is liable to a disease termed finger and toe, which practically destroys it. A large number of soils have been analysed, upon each of which the turnip crop has been partly or wholly destroyed by this disease, and these analyses showed that in every case there was a deficiency of either lime or potash in the soils. Now, had the farmers obtained the analyses of the soils before they farmed them this loss would have been prevented, for the analysis would at once have shown what was required to bring each soil up to a normal state of fertility, and this might have been first applied.

The previous chapters have clearly defined what is the normal condition of a soil. It now remains to consider what manures are most suitable for use to supply any apparent deficiency.

For the general improvement of soils, slowly acting manures are preferable. The various substances used for supplying lime have been previously mentioned. Phosphoric acid will be applied either by bones, superphosphate, or ground mineral phosphate. Bones will also contain sufficient nitrogen. Otherwise nitrogen will have to be applied in some slowly decomposable substance, such as shoddy, wool waste, fish refuse, &c. Kainit will supply any deficiency of potash unless it has to be incorporated with another manure or transported long distances, when muriate of potash is best used.

A good manure for the general improvement of the soil will be—for heavy soils, 4 cwt. per acre of bones; and for light land, 4 cwt. of superphosphate, 2 cwt. of kainit, and 5 cwt. of shoddy, or of rape dust, per acre. In either case this would be an initial outlay of about 40*s*. per acre; when capital will not permit such an outlay, smaller quantities rather than other and cheaper substances should be used. When land needs lime this must be applied at once, irrespective of any manures which may be subsequently required. If the immediate application of lime be impracticable it will yet be better to postpone the application of other manures, especially soluble ones, until after the application of lime, as they will be far more likely to be retained in the soil and prevented from being washed away than if the lime were absent.

Having given to the ground its essential and fundamental constituents, the application of artificials to the various crops will follow. The farmer will be guided in his choice of substances by several considerations; but principally he should endeavour, and consider it an axiom of good practice, that the increase in the crop immediately succeeding the application of a manure should recompense him for its application. A little consideration will show that this is really the only way in which artificial manuring can be made thoroughly profitable. Taking average crops, the plant is in the soil for about six months of the year; in the other six months there is very little, if any, call upon the soil constituents. During this dormant period large quantities of rain fall, as will be subsequently pointed out, and this will wash the soluble plant food, especially nitric acid, into the drains. Now, if the crop preceding this wet period repaid for the application of the manure to it, then the farmer will not suffer much by the loss of constituents which takes place, and will at least know it is as small as possible.

The next principle in the application of manures has regard to the nature of the soil. The application of manures to light sandy soils differs essentially both as to the mode of application and the substances employed from that to heavy land.

Light soils.—The lighter the soil the greater the necessity to use manures rapid in their action and easily decomposed, and to use such in quantities only just sufficient for the growth of the succeeding crop. Further, on light land, the various substances should be applied separately, each substance just at the time when the crop requires that special constituent which the manure supplies. For instance, in the growth of wheat upon light land the phosphoric acid will be applied in the autumn with the seed. Phosphoric acid, as we know, is not washed out of the soil. The nitrogen, which will for the most part not be required until the spring, is best applied then, in some easily soluble condition, such as nitrate of soda or sulphate of ammonia, the former being preferable.

But there is another important consideration which must not be overlooked. Whilst the main call of a plant for nitrogen is in the early period of its growth, yet, in all probability there is a slow absorption of nitrogen throughout the subsequent period of growth. It will be necessary to consider whether the soil has a reserve fund of nitrogen to meet this demand. The analysis will show this; if it has not, then, besides the top dressing of soluble nitrogenous manure, a sufficient quantity of a slowly decomposing nitrogenous manure must be also applied, the decomposition of which shall be contemporaneous with the growth of the plant. The reason why guano has proved such a valuable top-dressing is probably because it supplies this want.

The application of slowly decomposing nitrogenous manures, such as fish, blood, or wool waste, is sometimes permissible on light land, and is found well suited to those plants which, like the hop, require a somewhat constant though small supply of nitrogen.

Heavy soils.—Slowly decomposing materials are, however, applied most profitably and preferably to heavy land some months before the young plant begins to need their constituents. Moreover, manures will be applied to heavy land which are likely to lighten it. Of course upon light land the reverse will be aimed at. Heavy land appears peculiarly adverse to some manures, especially nitrate of soda. Upon many heavy clay soils the application of nitrate of soda is attended with most damaging results, the land becoming excessively wet and unmanageable—at least so it is reported. Sulphate of ammonia does not appear to have this effect, and has certainly yielded better results upon some heavy clay land than could be obtained by the use of an equivalent of nitrate of soda.

When a crop is continuously growing, as is the case with grass for instance, it becomes possible to vary the application of manure, and to take less consideration of the nature of the soil, but it must not be forgotten that these plants have a more vigorous growth in the spring than during any other period, and are therefore to such extent similar to other crops, and require similar treatment.

Passing now to the second object of manuring, viz. to improve the condition of a certain crop or crops, we must consider this under three heads. Firstly, the ordinary course of rotation; secondly, permanent pasture; and thirdly, continuous growth.

The ordinary course of rotation.—In this it has been the universal custom to put nearly the whole of the manure on the turnip crop of the first year. It is probable that this method is the best possible, saving as it does time and subsequent labour, and giving the largest returns. Farmyard manure will be the staple manure thus used, the quantity per acre depending upon the relative amount of arable to grazing land, and the number of stock kept. To augment the phosphates in the manure is advisable and necessary, and it is for this purpose that superphosphate is so largely employed. At least 3 cwt. of superphosphate per acre may be applied with advantage. Where ground mineral phosphates are employed, it is best to mix them into a compost with the farmyard manure beforehand. Phosphate of lime, so treated, is by the decomposition of the farmyard manure rendered more soluble than it was before such treatment, in the same way as the decomposition of the gelatine in bones renders some of the phosphate of lime in them soluble. But, wherever it is possible to use superphosphate, this will be found better than finely ground mineral phosphate. Experiments have shown that, whilst the ground mineral phosphate on anything but very poor soil does not repay its cost in the increased turnip crop, an outlay of 10*s*. to 12*s*. per acre on superphosphate will be amply repaid.

Next to swedes in the order of rotation comes barley. If the swedes have been fed off on the land no manure will be required, but if the swedes have been consumed away from the land, then it will be advisable, if not necessary, to add some nitrogenous manure to the barley, either when sowing it or a few weeks afterwards. For this purpose we may most advantageously employ guano along with the seed, or afterwards as a top-dressing nitrate of soda; this, like all top-dressings, should be put on during wet weather. The seeds which are sown along with the barley, and which form the crop of the third year, will require no manure. After the seeds the wheat closes the rotation. As a rule, and if there has been a good crop of seeds, it requires no manure, or, if any, it is best a phosphatic manure, such as a mixture of superphosphate and bones in equal proportion. If the barley received no nitrogenous manure in the spring, it will then be well to apply a little to the wheat. For this purpose, 1 cwt. to 1½ cwt. of guano or of nitrate of soda may be used as a top-dressing early in the spring.

There are very few data to guide the farmer in the choice of his nitrogenous manure for top dressing. Leaving out soot for wheat we have nitrate of soda, ammonia salts, and guano. Some of the peculiarities of nitrate of soda have already been pointed out. It may be remembered further, that nitrate of soda is more energetic and rapid in its action than ammonia salts, and ammonia salts are more active than guano. Moreover, these substances are liable to be washed out of the ground in the above order; nitrate of soda first, guano last. Hence, in applying them, the farmer must have regard not only to the nature of the soil, but also to the rainfall.

From this study of the manures required by the ordinary rotation, we learn the simple and easily remembered facts with regard to the various crops, that

Roots require Phosphate,
Cereals require Nitrogen,
Legumes require Potash.

If, therefore, to each crop in an ordinary course the special substance it is mostly benefited by is applied, a maximum of crops is obtained, and the land at the end of the rotation is left more fertile than it was at the commencement.

It has been shown that these fertilising materials are subsequently found in the soil unequally distributed; thus, phosphates for the most part are retained in the surface soil, potash is washed into and retained by the subsoil, while the tendency of nitric acid is to be washed away. Whether this distribution plays any important part in the economy of nature is not known, but probably it is not mere chance that so distributes the food of plants.

Permanent pasture.—At the present day, when the tendency of English agriculture is to increase the extent of permanent pasture, the maintaining of this in a due state of fertility must be of primary importance. As the growth in a pasture is continuous, slowly decomposing manures are best suited to it. Again, we know that the nutriment of the grass mostly lies in its phosphatic matter, which passes largely into the milk or meat and so leaves the farm. Where a large quantity of farmyard manure is made on dairy and stock farms, it will be used largely upon the permanent pasture, but it must be augmented by phosphatic manure; where there is not enough farmyard manure made to manure the whole of the pasture, as well as the arable land, more nitrogen is required. To supply this and the phosphate of lime as well, nothing surpasses bone, and 6 cwt. per acre every few years will upon good permanent pasture amply repay the cost. The expense of bones, however, is great, so that some prefer to use mineral superphosphate as a source of the phosphate of lime and soot, or nitrate of soda, for the nitrogen. Potash salts improve the grass on light land to a considerable extent, and where it is very rank salt may be applied with advantage.

Continuous growth.—We now pass on to the manuring of land where corn crops are grown continuously year after year. The object of the farmer is to maintain the fertility of the soil. To do this, he must replace everything that comes out of the land of which the supply in the land is limited, and also take into account the quantity of substance lost by the drains. Moreover, he must keep the land clean. In returning to the land the materials taken off it, the chief consideration will be the use made of the straw, for in the straw of wheat there is six or seven times as much mineral matter as in the grain, and in the straw of barley three or four times as much. If the straw be made into farmyard manure and applied to the ground, then only the constituents of the grain and the loss will need to be replaced in manure. In such a case, sufficient nitrogen will be returned in the dung, if made by well-fed cattle, to supply all the demands of the crop, and the chief manure necessary will be phosphoric acid. If the straw be sold off the land, then the manure must make up for both wheat and straw, and while the quantity of phosphoric acid is greatly increased, there will also have to be added a very considerable quantity of nitrogen. Next to phosphoric acid and nitrogen, potash will form the most important substance removed from the soil, and this will have to be replaced, especially where the soil approaches to a light character. But in heavy clay soils there is generally a sufficiency of this substance, and as continuous growth is mainly practised on heavy or somewhat heavy land, potash is only required after some years, and very occasionally.

Continuous growth is at all times difficult, and should not be attempted without due forethought; very few succeed in making it profitable, many fail. Of the few successful ones, Mr. John Prout, of Sawbridgeworth, stands unique, and he has admirably described his practice and its results in a small book on 'Profitable Clay Farming.' As manure for wheat, Mr. Prout uses 5 cwt. of a mixture of two parts bone to one of superphosphate in autumn, a top-dressing of 1½ cwt. of Peruvian guano in February, and subsequently 1 cwt. of nitrate of soda in May. For barley 5 cwt. of the phosphate mixture and 1 cwt. of guano are drilled in with the seed, and 1 cwt. of nitrate of soda is applied as a top-dressing later in the season. These are heavy dressings, and in both instances 3 cwt. of the phosphate mixture would probably be ample.

Effect of mixing manures.—It is evident that not merely the ash constituents, or mineral matter, of the plant must be returned to the soil, but also the nitrogen of the organic matter. As will have been seen the manures by which this may be done are most numerous. Now experiment leads us to suppose that the effect produced by different manures mixed together depends to some extent upon their relative proportions. Some experiments upon the relative value of manures for the continuous growth of wheat, conducted at Woburn by the Royal Agricultural Society, will illustrate this. The soil yielded naturally 433 lbs. of wheat per plot. The increase above this quantity, presumably due to the manures, was for

200 lbs. ammonia salts = 50 lbs. nitrogen	Plot	II.	323 lbs.
275 lbs. nitrate of soda = 50 lbs. nitrogen	„	III.	171 „
Potash, soda, magnesia, and superphosphate .	„	IV.	105 „
Potash, soda, &c. + ammonia salts	„	V.	1,047 „
Potash, soda, &c. + nitrate	„	VI.	979 „
Potash, soda, &c. + 2 (ammonia salts).	„	VIII.	1,170 „
Potash, soda, &c. + 2 (nitrate)	„	IX.	985 „
Farmyard manure = 100 lbs. nitrogen	„	X.	303 „
Farmyard manure = 200 lbs. nitrogen	„	XI.	601 „

It is a striking fact that, where the farmyard manure was simply doubled, the increase in yield was doubled. But when we consider the mixtures a very different result appears. Thus Plot V contains the same as Plots II. and IV combined. But by merely combining these manures the increase is more than double what they gave when applied separately Thus—

Plots II. + IV. = 323 + 105	=	428 lbs.
Plot V.	=	1,047 lbs.

The same holds good if we compare the increase of Plot VI. with that of Plots III. and IV Again, if we compare Plots V and VIII., and then VI. and IX., we see that doubling the ammonia salts in the mixture produced a beneficial result, but that doubling the nitrate of soda had no effect. There can be only one deduction from such figures, namely, that the relative proportion in which manures are mixed materially affects the results they give. It remains for future experimenters to follow this up, and perhaps arrive at some definite conclusions as to the best relative proportions for various crops. To the practical farmer they teach this lesson, that whilst it would pay to double the quantity of a general manure like farmyard manure, it would not pay to apply the superabundance of a special manure like nitrate of soda. These experiments also indicate that what we require to know is, what are the smallest quantities of manure which will yield the best results?

Agricultural experiments on manures.—The arguments in support of all such principles as have been laid down regarding manures are mainly based on experiments conducted in the field. Beware of jumping at conclusions from field experiments.

Agricultural experiments are immensely difficult to conduct, the results they give are applicable only to the exact conditions which yielded them, and those conditions are never alike for two years running. Hence, only after very many years and much patient labour can any reliable information be obtained, and then only provided the experiments have been conducted by well qualified and unbiassed persons. These conditions are rare. Farmers should beware of making agricultural experiments; and not waste their money, their time, and their land in making them, unless they are peculiarly qualified for such work, have the guidance of a thoroughly scientific man, and are not dependent upon their farm for a livelihood. The farmer has to farm, and to farm profitably, to raise the greatest quantity of substance, on the smallest extent of ground, in the shortest time, and at the least expense. It is the duty of the State and Societies to undertake such experiments as may be necessary for the solving of questions which deeply affect the agriculture and welfare of the nation, and the cleverest of farmers have done very little by making experiments themselves, and have probably never made them pay.

Expense of manures.—Numerous and extensive as have been the experiments on the relative value of various kinds of manure, little has been done, comparatively speaking, to see how small or how large are the quantities which prove most profitable. In most of the experiments hitherto made the manure has been applied year after year in exactly similar proportions, but in no single year have the manure constituents been again taken off the ground even by plants and drainage combined. Consequently the land has been constantly increasing in fertility, and the experiments have never been two years exactly alike. Hence they have been of a theoretical and semi-practical value, rather than of a direct pecuniary value, which, after all, is the final end and aim of all of them.

To the farmer the quantity of manure as influencing the cost must always be a matter of primary importance. Mr. Prout spends 2*l.* 10*s.* per acre per annum on manures, an exceptional sum. Thirty shillings an acre is a fair sum for all ordinary purposes, and even 20*s.* an acre, spent judiciously, will amply repay the outlay. A farmer must not sacrifice his crop for the sake of saving a few shillings an acre. At the same time the farmer should look at the cost of manure, and ask if it is not possible to obtain equally good results at a smaller outlay, by purchasing cheaper, though equally efficacious, manures. The general tendency of farmers seems to have been either to disregard artificial manures, or to use them in excessive quantities.

In the combination of manures, which experiments have shown to be desirable, great skill can be exercised. Many farmers have felt the want of the necessary knowledge, and manure merchants endeavour to supply this want by manufacturing special manures for various crops, which manures purpose to be made in accordance with the experimental results, or upon the advice of some eminent authority. The true value of these manures, and the advisability of not purchasing them, have been previously mentioned. The farmer can always obtain from the chemist the information the manure manufacturer has obtained, and can mix for himself the necessary constituents. With this further advantage, that the chemist in advising a farmer can consider the special requirements of the farm, its soil, climate, and cropping. But in advising the manure merchant or manufacturer he is obliged to follow more general considerations. The farmer is often instructed by some wiseacre how to make his own dissolved bones or superphosphate. He might as well attempt to make his own plough. The appliances with which manure manufacturers surround themselves, the competition which they have to contend against, and the comparative case with which manure can be conveyed, enable them to produce a far better material, and to sell it at a less price than it would cost the farmer who made it himself. Moreover, home-made manures are, as a rule, wet and lumpy—in such a condition, indeed, that it is almost impossible to apply them to the land.

Purchase of manure.—It has been previously stated that the substances required should be bought and mixed in accordance with the advice of a skilled adviser. Then the greatest precaution should be exercised by the farmer in seeing that he obtains what he orders. To ensure this no manure should be bought unless it is guaranteed either 'pure' or of a standard quality: that is, to contain a definite proportion of one or more certain constituents. Even this will not be sufficient. The farmer must prove that he gets what is guaranteed. To this end he should take a fair sample of the manure and have it analysed, to see if it comes up to the guaranteed standard. A fair sample is obtained by mixing together carefully about ten handfuls of manure, each handful taken from a different bag, breaking down lumps so far as possible to obtain a uniform and thorough mixture. A couple of handfuls placed in a box will be a fair sample; it is also advisable to keep a large portion of the remainder in case of any dispute. If the analysis proves the manure to be substantially what it was guaranteed, then pay for it. If not what was guaranteed, then the farmer is at liberty either to return the whole or by arrangement to keep it, and pay for the manure in accordance with the analysis. Never use the manure until the analysis is obtained. When we consider that the manure bill on a farm is one of the heaviest, it will be easy to realise the necessity of the farmer getting his money's worth.

Application of manures.—With regard to the method of applying manure, the best general rule will be to apply the manure so far as possible in the same way as the seed has been sown. Thus, where the seed is drilled let the manure be drilled also, at the same time, and a little beneath the seed. Drilling machines are now made which perform this operation perfectly; the seed and the manure pass into the soil by different channels and never come in contact with one another, the seed being deposited a little above the manure. Where the seed is sown broadcast, the manure, if possible, may be sown in the same way.

Composts.—Before applying manures it is usual to mix them with some substance, or substances, and with one another, so as to dilute them and enable them to be more evenly spread over the ground. There are many such mixtures made upon the farm, and to them is given the general term composts. All refuse substances about the farm should be collected together for this purpose, the clearings of hedges and ditches, leaves, weeds, and similar organic matter, being mixed together with a little earth, and sometimes lime. The road cleanings of the farm should be collected for this purpose. Ashes should be carefully kept to mix with the artificial manures, than which nothing is better to dilute them; where ashes are not to be had in sufficient quantity, earth is often used. Where bones are to be used on the ground it will be well to place them in a heap, and moisten it either with water or liquid manure. If kept in this moist state for six weeks the bones undergo a partial decomposition, rendering, as already pointed out, the phosphate of lime more soluble. Upon light soils, and especially on soils deficient in lime, it is injurious to apply superphosphate with or near the seed; strong acids affect if they do not altogether prevent the growth of the seed, and are at all times injurious to vegetation. Most superphosphates contain a certain amount of free acid; where then superphosphate is wanted for light, sandy soil, the free acid of the superphosphate should be neutralised before applying it to the land. To do this lime must not be used, for then, in addition to the free acid becoming neutralised, the soluble monocalcic phosphate or soluble phosphate would be converted into the insoluble tricalcic phosphate. In such cases the following course may be pursued to advantage. A small quantity of ground bones, after being fermented as above, are intimately mixed with the superphosphate some weeks before it is required, and the mixture is left to stand in a dry place for a week or two. The acid will slowly combine with the bone and become neutralised, while the solubility of the soluble phosphate will not be materially changed.

Compensation for unexhausted manures.—It has been laid down as an axiom that if manure be judiciously applied its outlay will be repaid by the crop for which it has been used. A failure in the crop can alone prevent this, and such a failure can only be due to unavoidable causes of weather or subsequent bad management. Whatever loss is thus incurred would and ought to fall upon the farmer himself. Consequently, in a proper system of cultivation, there should be no such thing as a value to unexhausted manure where the manure has been applied in a rotation for the purpose of raising the produce of a certain crop. Of course this assumes that the farmer has reaped or gained the benefit of the crop. That with the present method of manuring there often are after-effects of manure none can deny, but that is due to an erroneous method of applying artificial manures; so long as that method lasts, so long also will the demand for compensation. Where, however, manure is applied, the benefit of which is felt for years—that is, such manuring as has been described under the heading and for the purpose of the general improvement of the land—then, the farmer has in the land his capital, so to speak, and should he leave his farm before the effect of those manures may reasonably be supposed to have ceased, he then, of course, is entitled to be paid for the benefit which the landlord or incoming tenant obtains. It must be remembered that lime, and nitrate of soda, and strong nitrogenous manures, have an exhausting effect upon the land. Thus, if the land be in good condition and nitrogenous manures be used solely, the large crops resulting will naturally take a correspondingly large quantity of plant food out of the soil, so that if the practice is continued without replacing this food the land soon becomes exhausted. Hence nitrogenous manures require great care in their use, and as sometimes used it would often be more just if the tenant gave the landlord compensation for having deteriorated his land.

The whole subject of compensation for manures requires study, to discover how far the effect of various manures is felt by subsequent crops. Compensation for the manurial residue of feeding stuffs should be based on the amount of nitrogen these contain, the nitrogen being valued at the current market price of nitrogen in nitrate of soda or ammonia salts.

CHAPTER XIII.

THE CHEMISTRY AND PHYSIOLOGY OF PLANT LIFE.

OUR knowledge of the chemistry and physiology of plant life is in one sense small, and yet again vast. Year after year many and diligent workers, of all nationalities, and in varied departments of science, discover and add independent facts to the knowledge of plant life which has already been attained. Some few have sought diligently for facts that they might complete the links of some chain of reasoning they have long been working out. But many, indeed the majority, have come across facts while searching for truths of quite a different nature. Some have been conscious of the value of their work; others, probably the greater number, have taken little interest in the subjects which they have accidentally illumined, and have thrown their new found knowledge into the sea of science, to be, perhaps, lost for many years, until brought to light by those who could appreciate its true value. Thus, innumerable facts have been collected which as yet are scarcely sorted, much less properly arranged; and hence there is considerable difficulty in deducting from them any principles which may be said to govern plant life. In this chapter it will be only possible to indicate roughly such principles and facts as are of interest, in considering the subject from an agricultural standpoint.

The plant consists of a certain number of chemical elements, which it procures from the soil and atmosphere. From these elements, which are all inorganic compounds, the plant builds up highly complicated substances, which are all organic compounds. The life of the plant is then the synthesis of organic matter from inorganic matter. When the plant dies decomposition at once sets in, and the complicated organic compounds become reduced to those less complicated inorganic compounds from which they were originally built up.

The most convincing proof of these properties is afforded by yeast. There are multitudes of small portions of matter essentially vegetable, which exist in water, and in water run the whole course of their existence. Such, for example, is yeast. The first fact which we know of these minute organisms is that they invariably spring from an organism exactly similar to themselves; in fact that living matter is not self-creative. It has been found that by taking the yeast organisms and placing them in various solutions of purely inorganic chemical salts, they are in no ways disconcerted, but flourish, and it is from such experiments that the law has been deduced, namely, that the vegetable has the power of forming living matter out of non-living matter.

Leaving aside for a time the nature of the changes which take place, we may at once consider the liquid itself. Pure water will not suffice. The liquid must contain some compound of carbon, such as carbonic acid, to supply the plant with carbon which will form the nucleus of the living matter, for all living matter consists of various compounds of carbon. There must also be present in the liquid other mineral or inorganic substances which can never be converted into what we understand by the term organic matter. These mineral or inorganic substances are partly combined in the plant with the organic substances, partly not so combined; but how they mutually help one another in the functions of the plant's life is very imperfectly known. The following elements must be present in the solution: carbon, nitrogen, phosphorus, oxygen, hydrogen, lime, and potash.

Given, then, a solution containing these substances, and in such a solution vegetable life will exist. Now, if these mineral matters are not present in, or if even one of them is absent from, the solution the plant will not grow; hence it follows that these substances must be combined with the organic matter, and serve as a means of retaining this organic matter in certain intermediate forms through which it passes, before ultimately assuming the forms in which we know it, and in which apparently it is freed from the mineral matter. If this were not so, then there could be no possible reason why the plant should not mature without some of these mineral substances.

The transformation of inorganic matter into organic matter constitutes the life of the plant, and distinguishes the plant from the animal, for the animal is incapable of forming organic matter out of inorganic matter; it requires for its existence the already formed organic matter of the plant. And it is for the support of animal life that the farmer grows his crops.

The simplest form of vegetable life is seen to be a small spherical or oblong cell. The most complicated form of vegetable life consists of nothing more than a number and variety of such cells.

The cell consists of a thin membrane or wall enclosing a semi-fluid mass, which mass contains a small spot of dark matter termed a nucleus. The semi-fluid mass which constitutes the living matter of a single cell, if this cell be itself a plant, is termed protoplasm, but where a number of cells congregate together to form a plant, then the cells become modified and changed, not only in shape but in contents also. Definite organic compounds are then formed and spread with more or less regularity throughout various portions of the plant. Some of these organic compounds or plant constituents —for instance, wood—cannot be digested by the animal stomach, so that all portions of the plant cannot be utilised by animals as food; hence that portion only which can be so utilised is looked upon as nutriment or the nutritious part of the plant. The value of a crop to the farmer is directly in proportion to the quantity of nutriment it contains. The plant, therefore, may be said to consist of two parts—the digestible or nutritious part, and the indigestible or non-nutritious part. The chemistry and physiology of plant life has, therefore, a direct practical value to the farmer, if it enables him to understand firstly, what are the substances that are nutritious, as compared with those which are without nutriment; secondly, where in the plant these substances are formed, and thirdly, what are the laws of nature which regulate their formation, and whether and how these are capable of being influenced or utilised by man.

This subject, therefore, will be divided into two parts:—

I. The nature of the constituents of plants.

II. How and where these constituents are formed in the plant, and the laws which regulate their formation.

I. The constituents of plants.

These compounds of carbon may for agricultural purposes be divided into two groups—those which do not contain nitrogen and those which do.

The non-nitrogenous constituents.—These will consist of carbon with the elements of water—hydrogen and oxygen. Of these compounds some have the special name of *carbo-hydrates.* This they have because of their peculiar composition of carbon, hydrogen, and oxygen, with always two atoms of hydrogen to each one of oxygen. Now, water consists of two atoms of hydrogen and one of oxygen, so that these carbo-hydrates are as if carbon were combined simply with water. If we place, therefore, the symbol for carbon C before the symbol for water H_2O we obtain CH_2O, and the substance would be, if such a substance existed, a carbo-hydrate. The principal carbo-hydrates of importance to the farmer are starch, sugar, and cellulose.

In order to subsequently explain some of the changes which take place in the plant it will be well to try and understand the composition of these three substances, which, besides being closely allied to one another, are capable of being converted into one another under certain given conditions, and these conditions occur in the crops of the farm. The chemical composition of these substances is:—

Starch	$C_6H_{10}O_5$
Fruit sugar	$C_6H_{12}O_6$
Cane sugar	$C_{12}H_{22}O_{11}$
Cellulose	$C_{18}H_{30}O_{15}$

Starch is found in most plants during some period of their growth. In some it forms the substance for which the plant is grown; thus, for example, potato, and rice, the latter the staple food of the Indian people, consist entirely of starch. There is a large proportion of starch in all the cereals; thus, in wheat, barley, oats, &c., over fifty per cent. is starch. If starch be taken into the mouth it becomes rapidly converted by the saliva into sugar, owing to the presence in the saliva of a ferment called ptyalin. It will be seen by the symbols that this change is due merely to the addition of the elements of water, H_2O. This change also takes place when starch is heated in boiling water containing a small quantity of acid. A similar change takes place in the plant during the ripening of the seed, and in all ripe fruits we find more or less sugar. Starch is found in roots, such as swedes or mangolds, or beet, during their growth; but at the time when they have reached their maturity sugar is present. The presence of starch in a substance is most easily determined by a solution of iodine, which turns starch a dark-blue colour, so that the merest trace of starch is easily detected.

Sugar is probably the result of a change in the starch due to the growth of the plant, and often denotes ripeness. This sugar may be either grape sugar, or fruit sugar, or it may be cane sugar. These and many other substances designated sugar—for instance, milk sugar—have slight but certain chemical differences. But while differing chemically, yet, they are probably alike, so far as nutriment goes, and are hence of equal value to the farmer for their feeding properties.

Cellulose.—There are two kinds of cellulose, though of slight difference chemically, yet of great difference practically. The cellulose of young plants is digestible, the cellulose of old plants is to a great extent indigestible. It was stated that the plants consist of a number of cells. The lining membrane of each of these cells is cellulose, and this substance when first formed, and for some short time after, appears to be soluble in the gastric juice of the animal's stomach. But as the plant matures, and the cells get compressed, this cellulose hardens and becomes converted into what is termed *woody fibre*, or lignin, and this substance, though chemically almost the same as cellulose, is practically widely different, having no use as nutriment to the animal, and if present in the food in excessive quantity becomes injurious; hence it is often spoken of as indigestible fibre.

Oil and Fat.—There are other compounds of carbon found in the plant which also contain hydrogen and oxygen, but they have relatively far less oxygen than the carbo-hydrates. Of such compounds are oils, fats, resins, waxes, &c.; of these the oils and fats are of most importance. They exist for the most part only in minute quantities, but in the seeds of plants they are often found in considerable abundance. The presence of the oil gives to such seeds exceptional value for feeding purposes, apart from the other constituents they contain. Thus in the seed of flax, or linseed, and in cotton seed, so great is the quantity of oil that, even after the main portion has been extracted by pressure, the part or cake which remains contains sufficient oil to make it a most valuable feeding material. Large crops of those plants whose seeds contain oil are grown solely for this oil; such are rape or colza.

The nitrogenous constituents.—Albuminoids.—The nitrogen of plants, so far as it affects their nutritive quality, exists as vegetable albumen, or, more properly speaking, as an albuminous compound. Albuminous compounds were formerly termed proteids, and are now more generally spoken of as albuminoids. There are two kinds found in vegetables, one which exists in a soluble form in the juices of the plants, and another which exists in a semi-solid or coagulated form in the seeds and other parts. Like oil, the albuminous compound finally reaches the seed and is retained there. The albuminoid of wheat may be obtained by a very simple process. If the ground seed, *i.e.* wheaten flour, be first made into a dough, and then carefully kneaded in the hands, while a small stream of water runs slowly over it, there will finally be obtained a thick sticky substance, from which nearly the whole of the starch has been washed away. This substance is *gluten*, the albuminoid of wheat. In the same manner the albuminoid peculiar to barley or oats can be obtained. An albuminous compound is also present in peas and beans, to which has been given the name of *legumin*. Practically, it matters not what is the exact form of the albuminoid; they are all for feeding purposes identical so far as we know. Chemically they possess this one essential in common, that they contain sixteen per cent. of nitrogen. They also contain small quantities of sulphur and phosphorus.

Amides.—These are compounds which appear to be direct derivatives of ammonia. Ammonia consists of nitrogen combined with hydrogen, there being three atoms of hydrogen to one of nitrogen; if we take away one of these atoms of hydrogen, we obtain a compound NH_2, which combines with organic matters as ammonia does with acids; the resulting organic compound containing this NH_2 is called an amide. Amides are found in plants in small quantities only. Asparagin, the essential principle of asparagus, is the best known. When better understood, it is probable they will throw some light upon the physiology of plant life. They are not present always in the same parts, nor even in the same proportions, and are very secondary and insignificant as compared with the albuminoids. Probably they do not act as food in the animal organism.

II. How and where these constituents are formed.

Having studied the substances which are of nutriment and without it, let us now pass on to those changes which take place in the plant, and lead to the formation of these substances, whilst at the same time we shall learn in what parts of the plant the substances are formed and finally stored. In order to do this, let us rapidly review the nature of a plant. We shall find it to consist of two parts, one below, one above ground. The part below ground is the root, the part above the stem. This stem will bear leaves, then a flower, then a fruit, and the fruit, seed; from this seed, under favourable conditions, a similar plant will grow to that from which it came. We will now consider the parts of the plant in order, and commence with the seed.

The seed.—The appearance of a seed and the great variety of forms which seeds assume are well known. If widely different in external appearance, they are not so in internal structure, they possess two distinct parts—an embryo, and a perisperm, enclosed in a coat or covering called the integument. The embryo consists of three parts, the plumule, the radicle, and the cotyledon, and flowering plants are divided into two great classes according as the seed contains one or two cotyledons.

We all know how, when we take off the integument of a bean, the interior easily divides into two parts; these are the cotyledons. A bean may be taken as an example of a dicotyledonous plant; wheat as an example of a monocotyledonous plant.

Stored up in the seed, in varying proportions, will be some or all of those constituents which have just been described, and also some mineral matters. Now let us try and discover some of the properties of a seed.

A seed may be kept in a shop for many months and no change take place, but no sooner is the seed placed in the soil than a change will immediately commence. A seed naturally possesses life, *i.e.* the power to develop under given conditions. Those conditions are heat, moisture, and oxygen gas. Thus if a seed be placed in a soil sufficiently damp and warm these conditions are met and the seed should grow. If it have lost the power to grow or germinate, it is dead.

Now it is not necessary that the seed should be placed in the soil in order to grow; so long as it obtains heat, moisture, and oxygen it is sufficient. Thus mustard and cress, or indeed any seed, may be grown up to a certain point upon a piece of stretched flannel, kept moist, and in a tolerably warm atmosphere, and any seed which will not under these conditions commence to grow—that is, to germinate—would not grow if placed in a soil. In this simple way it is easy for a farmer to test the germinating power of the seed he is purposing to use. Malt is simply barley which has been moistened and kept warm until it has germinated, then, when the germination has proceeded far enough, the germinated seed is heated to a temperature which kills it, and so prevents further change. This sprouting of the seed may take place even in the ear of corn, if after it is ripe there comes excessively wet weather before the farmer can gather in his crop.

It is evident then that nothing is required by the seed in the way of food for the early stage of its growth except the nourishment which is stored away in itself, and which moisture and warmth, and oxygen gas—that is the atmosphere—have brought into requisition. Now the food so stored up is in all cases sufficient to carry the embryo through a definite series of changes, with the following result: the radicle descends and forms a root or roots; and the plumule ascends and forms a small stem, on which there appear one or two small leaves, according as the plant belongs to a monocotyledonous or dicotyledonous order. The plant having arrived at this stage, the food stored up in the perisperm or cotyledons is exhausted, and the plant subsequently depends on the soil and atmosphere for its food.

The chemical changes which take place during the germination of the seed, owing to the great commercial value of the germinated seed of barley, or malt, have formed the subject of some considerable research, and are partially understood.

The very earliest product of the growth of the seed is a nitrogenous substance termed *diastase.* This is a ferment, and, acting upon the starch stored up in the seed, converts it into sugar, thus rendering it soluble, and so enabling it to pass at once into and nourish the developing plant. Where the seed contains oil this is oxidised, and finally rendered soluble and absorbed by the plant.

The Plant.—In the resulting minute plant the root will be white, the stem green. Inside the stem will be found the sugar resulting from the changed starch; at the tips of the stem and root, and in the integument will be found cellulose, and finally there will be present the green substance giving colour to the stem and termed chlorophyl. Having once reached this stage, the plant is capable of existing upon the food which it finds in the soil and air, and which have been described in a previous chapter. So far as possible let us see how it does this.

The root as it grows downward grows at its tip, and only there and at the tips of every offshoot does it absorb nutriment. These tips are composed of a number of cells, which being always newly formed are most tender. To protect them the whole tip is covered with a sheath of cells, apparently much harder than those of the growing tip, and so enabling the root to find its way, without injury, between the particles of soil. In the growing plant the root tip is acid, thus it is that it not only absorbs substances in solution in the soil, but, further, has a chemical action upon more insoluble substances, and renders them soluble and so capable of being absorbed. Thus the root obtains the mineral matter for the plant. The composition of the ashes of plants shows that the roots of one plant will absorb certain constituents, while the roots of another plant absorb other constituents. This forces us to the conclusion either that the roots have a discriminative or selective power over the substances at their disposal, or else that they absorb all alike, and that by a subsequent process the plant ejects what it does not require. The first supposition is accepted at the present day, though the excretory theory was formerly held. The liquid absorbed by the root is carried to the stem.

The stem itself, so far as we know, exerts no influence in obtaining food; it grows, as also do its branches, at their tips, like the roots, the tips in this case being termed buds. The most important structures of the stem are the vascular bundles of long cells and vessels, which, running the whole length of the stem and branches, open up a network of passages, and form a communication between the various parts of the plant, as our veins and arteries do through the various parts of our body. The chief appendages of the stem are the leaves.

If, by the aid of a microscope, we examine the structure of a leaf, we shall note that the under surface is studded with an immense number of cells, having a semi-circular or kidney shape, and two of which are always placed together, their concave sides being adjacent. These form what are termed *stomata*, and between the two cells there is an opening into the interior of the leaf structure, and hence into the vascular and circulatory system of the plant. These stomata play a most important part in vegetable physiology. Firstly, it is through them that transpiration takes place, and they are said to close in dry weather, and open in moist. Secondly, it is by their means that the carbonic acid of the atmosphere is taken up by the plant, for through them the plant breathes, and thus they at once bring the carbonic acid into contact with the chlorophyl by which, as we shall presently see, it is utilised. Finally, there can be no doubt that these stomata are the means by which plants obtain certain diseases of a fungoid nature, which invariably commence at the stomata of the leaves.

Chlorophyl.—One of the most striking peculiarities of nearly every vegetable substance is the presence of the green colouring matter chlorophyl, interspersed in a very regular manner within the cells of the plant tissue. Chlorophyl is a most complicated vegetable compound, and though it has formed the subject of much study, yet little is known of the stages which precede its formation or follow its disappearance. The green colouring matter of the lower vegetable organisms has been found to be identical with that of leaves. It may be considered proved that chlorophyl is the immediate cause of the assimilation of inorganic carbon from carbonic acid, and of its subsequent conversion into organic carbon. Chlorophyl decomposes carbonic acid. It is only capable of doing so, however, in the light. Even a plant containing chlorophyl will lose its green colour when light is excluded. This is how celery and endive are bleached, and thus it is presumably that roots are white. Plants which have no chlorophyl do not decompose carbonic acid, therefore such plants cannot live on the atmosphere, nor elaborate for themselves sap. Hence we find that they invariably live on the juices of some plant having chlorophyl—that is to say, they are parasites, *e.g.* mistletoe. Many such parasites infest farm crops, thus the broomrape and dodder, which belong to this category, are often to be found on the clover crop.

The chlorophyl in a plant may disappear, and, as a subsequent growth of the same part, its place be taken up by starch. The starch so formed in the leaf is capable of being converted into sugar, which being soluble, can traverse the intercellular spaces or vascular tissue, and may be again converted into starch in some other part of the plant. This does take place in the formation of the seed. Take for instance, wheat; probably all know from experience how sweet the ear of wheat is in the early stages of its growth, and before the sugar has been again con verted into starch. It may here be stated that a solution of sugar is capable of dissolving albuminoids, so that this also accounts for the method by which albuminoids are carried to the seed.

Growth.—It will thus be seen that the root and leaves combined gather the food of the plant, that this food is mainly elaborated in the leaf by the action of that wonderful and universal green matter chlorophyl, and that the elaborated material is then carried by the vascular system and deposited in the seed in an insoluble condition. The life of the plant is ended with the production of seed.

To a large extent the matter in the seed will be albuminous. Now it is this albuminous compound, stored up in the cotyledon or cotyledons, that forms the very earliest of plant food, upon which with the addition of water the seed is able to germinate, and form the elementary root and stem. Hence we arrive at this curious fact, that the substance last formed in the mature plant is the substance first needed by the young plant. It is so with the whole vegetable and animal world, including even man. Thus milk, which is the first staple of the offspring's existence, is the last product of the parent's growth. The first essential food then of the young plant is partly a nitrogenous compound. The importance of nitrogen in the early stages of growth is indeed so great that, after the whole of the food stored up in the seed has been exhausted, there is still a demand for more nitrogen; hence it is that a top-dressing of nitrogenous manures is so beneficial in the spring, and has become so universal a custom in good farming. As the plant matures it will require phosphates; hence there appears to be a change in the diet of plants as they advance in growth.

Whatever the changes which take place in the growth of the plant, the result is the deposition of certain matters constituting its substance. This deposition, so far as we are now concerned, may take place in the root itself, in the stem and leaves, or in the seed. Thus in the turnip crop and potato the deposition is in the roots, or, more properly speaking, in the bulbs or tubers, in the clover crop it is in the stem and leaves, and in the wheat, barley, and oat crop it is in the seed.

Decay.—A plant having matured, at once commences to deteriorate. This will perhaps be best explained with, say wheat, or any cereal. The first stage of the plant is growth; the second appears to be the accumulation of matter, which shall subsequently go to form the seed; and the third part is the maturation of the seed; subsequently the plant dies. It is probable that, before the seed is entirely formed, the absorption of food by the plant has ceased, the substances have been built up in it which will be required to form the seed, and these now are gradually absorbed by the seed, leaving the rest of the plant exhausted. Hence we find that, if a stem of wheat be cut off from the roots shortly before the seed is ripe, the seed will nevertheless continue to ripen, being fed by the juices which remain in the stalk. But should the plant be allowed to over-ripen, then its nutritive qualities will be rapidly diminished by the conversion of the valuable nutritive properties into cellulose and woody fibre. Hence, in the reaping of wheat and cereals, it is of importance not to let the corn get over-ripe; nor, on the other hand, should it be cut too soon, when the nutriment is in the stalk, and not yet in the ear, for even though the straw will under such conditions be more than usually nutritive, yet the seed will very materially suffer.

Similar changes take place in clover, grass and all green crops. Thus, during the early period of their growth, the plant is continually increasing in size and weight, until finally it begins to flower, and then, as the seeds begin to draw up the nutriment from the stem, the stem begins to dry at its base. As a green crop it has now reached perfection, and should be cut. If cut before this period, or eaten off by sheep, far less nutritive matter is obtained than should be, whilst if allowed to remain longer on the land, changes take place as in the wheat, which deteriorate it. Thus for every week a green or fodder crop remains in the land after the period of ripeness it deteriorates: firstly, by loss of moisture, so that the yield weighs less; secondly, by loss of albuminous compounds, so that the crop is less nutritive; and, thirdly, by the formation of indigestible woody fibre, and a rapid decrease in the quantity of soluble matter contained in the crop, which not only make it less valuable, but more difficult of digestion.

Somewhat analogous changes take place in root crops. Root crops are due to an abnormal growth. They belong to plants which are biennial, and come to perfection only in two years. The first year the plant stores up in the expanded bulb, or root, the nutritive matter which it has obtained from the soil and atmosphere. In the second year this root supplies the nutriment to the plant, which enables it to grow and produce seed. Except for the purposes of obtaining seed, this second year's growth is not permitted. The root is taken up out of the soil when it has attained perfection; in fact, for the sake of preserving it, the root is taken up a little before it is at its best, and, if carefully stored, it is found that the changes subsequently take place which would have taken place in the field.

Thus have been briefly sketched one or two points in connection with the chemistry and physiology of plant life; an endeavour having been made not to introduce theory, but so far as possible fact, and that such as should be of practical benefit, and elucidate subsequent chapters.

CHAPTER XIV

SEED—THE ROTATION OF CROPS.

Seed.—With the exception of the potato, all our farm crops are produced from seed. The quality of this seed, its variety, and the methods of its application, are of importance, and must now be considered.

Germinating power.—In the last chapter it was pointed out that only those seeds which were capable of germinating were able to produce crops, and that all others were dead, a simple means by which a farmer could himself test the germinating power of his seeds was also given. We must now consider what are the circumstances under which seeds retain or lose life? This is a subject of interest to the farmer, inasmuch as his crops depend to a very great extent upon the seed he sows. The causes of death in seed are, first, the abstraction of water. Every seed contains naturally a certain proportion of water. If this water be driven off rapidly, or lost slowly, the seed dies. Thus if the seed be kept in an exceptionally hot place it will rapidly die. Even the slow loss of moisture, consequent on the drying up of the seed by age, is sufficient to kill it. Hence seeds by being kept become incapable of germination, or dead. The time which different seeds can be kept without injury depends, therefore, upon their power of retaining moisture, and this depends greatly on the thickness of their outer coats; hence seeds having thin outer coverings do not last so long as seeds possessing thick, and dense, integuments. It is stated that a few seeds of the latter class retain their vitality for nearly a century. The accounts of wheat preserved in the pyramids of Egypt retaining their vitality are, however, probably mythical. For agricultural purposes it may be taken as a safe rule that seeds should not exceed one year in age. Age, therefore, or, chemically speaking, loss of moisture, is the first cause of dead seed.

The second cause of seeds not germinating is unripeness when gathered. If seeds be gathered before they are mature, they will not have stored up in them that food which is required by the young plant, and they will not germinate. Such seeds present a shrivelled up appearance.

The third cause of death to the seed is injury. If a seed be broken or even bruised in the processes which take place between gathering it and sowing it, and which it is more especially liable to when being threshed out or cleansed, then it will not germinate.

Lastly, there are amongst the good seeds usually some few which, though structurally perfect within, have an abnormal external covering, so thick and hard as to resist the entrance of the water necessary for germination.

Until recently sufficient attention was not paid by farmers to the germinating power of the seed they used, and when they suddenly woke up to the fact that it was important, and experiments were made, it was not infrequent to find that only 15, 20, or 25 seeds out of every 100 were capable of germinating. The others were dead.

From the preceding remarks it will be seen that those seeds should be fully ripe which are to be employed for raising another crop. Now it is found that the plumpest seed will, as a rule, produce the best crop, and therefore the object of the farmer is to select the largest seeds from a crop, and use those only for sowing. This rule, however, is subject to exceptions; thus seeds require to be somewhat strong before they are suitable for sowing as seed. If, therefore, a crop is grown not merely to produce seeds for sowing, but to produce seed for some special purpose—such as barley for malting—then the majority of the crop is not likely to be fit for use as seed; it will not be strong enough, and some of the smaller grains which are separated by winnowing must be taken. After they have been thoroughly cleaned the finest of them are then selected for seed.

Purity and cleanliness.—There grows up in nearly every crop a series of weeds peculiar to that crop, such, for instance, is the poppy in the wheat field; as these weeds come to seed about the same time as the crop, their seeds get mixed with the seeds of that crop. It is essential that these weed seeds should subsequently be separated, and not resown, and upon the thoroughness of these separations will depend the purity and cleanliness of the resulting seed. This cleanliness is obtained by, firstly, sifting the seed. It is passed through a revolving perforated cylinder; through these perforations the small seeds pass, but the larger seeds will not pass, so are collected separately. Secondly, by winnowing—that is, causing a strong draught of air to pass over the seed; this carries away particles of straw, &c., which being lighter than the seed are blown away, but being larger than the seed did not pass through the perforations. These operations, of course, add to the cost of the seed, but the farmer is compensated in many ways; for less seed is required to be sown, the resulting crop is of better quality, and it is freer from weeds.

Change of seed.—Assuming that the farmer has employed good germinating seed and clean seed, his crops for some time will be all that can be desired, and each year will supply him with seed for the next. In the course of three or four years, however, it will be found that the crop—and this applies specially to wheat and other cereal crops—is deteriorating. It will now be necessary to seek some new seed. This is termed the change of seed. In seeking for new seed, not so much the variety will be considered as the conditions under which the new seed has been grown, and it will be desirable to select seed which has previously been grown under conditions less advantageous than those it will now be subject to. Thus seed should be selected from a colder district, from a poorer soil, and from a soil of a different character. If, therefore, it is required to bring seed from a superior to an inferior climate, such as from Australia to the South of England, it can only be done in two stages: first by taking the seed to a colder and less favourable climate and soil even than the South of England—say to Scotland—and then subsequently transferring it to the South of England. It would here regain to a great extent the vigour and properties it had originally in Australia.

Variety.—The last and perhaps most important consideration with regard to seed is the variety which it represents. There are of all cultivated plants many varieties, some more suited to certain conditions, either of soil or of climate, than are other varieties. To secure these varieties and to maintain them distinct the seed used for sowing must be scrupulously selected. Seed possesses a strong natural tendency to produce seed like itself. It throws upon its progeny the character of their parent. This is termed 'heredity,' and owing to this natural law there is an ever-recurring tendency in plants to reproduce seed having the characteristic peculiarities of the seed from whence it sprung. If, then, man selects certain seeds, all of which have certain peculiarities, he is sure to obtain a crop yielding seed possessed of those same peculiarities. Thus it is that selection becomes so valuable, and the seed produced of such high quality, when care has been taken in its continuous selection; and thus it is, also, that the many varieties of our farm crops which exist have had their origin. There is, however, a constant tendency in these varieties to revert back to the original and inferior stock, so that constant selection is necessary to eliminate these throw-backs, and so keep up the standard of the variety. For example, with oats there will be a tendency for white oats to appear among black and black oats among white, and, if these two varieties are to be maintained distinct, it is necessary by selection to eliminate the recurring accidental tendency to deterioration. This selection would be useless if the natural tendency of the seed was to produce indiscriminately seeds of various character.

It is possible for every farmer who desires to devote his time to it to produce a variety specially suitable to his land and climate; and it is only by the production of new varieties that we can hope to attain perfection. In order to produce a new variety of a cereal, for instance, it is necessary to understand to what causes the changes in plants are due. Firstly, they will be due to the food and surroundings of the plant so far as these are affected by the soil or climate of a place; changes produced by these causes are, as a rule, confined to the individual plant and not transmitted to its descendants. Secondly, there will be sports, the causes of which are completely hidden; these may be transmitted to several descendants. Thirdly, there will be cross-breeding, which may be natural or artificial—that is, produced by the interference of man, in which case it will include selection. By cross-breeding an offspring is obtained possessing the peculiarities of both parents. This cross-breeding may be between two species or between two varieties of the same species, each having permanent characteristics. The breeding is brought about by applying the pollen of one plant to the stigma of another. The production of a new variety does not end here. The variety must be cultivated. It will then be found that some of the plants revert back to one or other of the parent forms, whilst in some their mixed nature is intensified. The seeds of the first kind need to be carefully picked out and discarded. Hence, after the production of a new variety, a process of selection is necessary, which should be continued for three or four years, until the peculiarities of the new variety have become fixed, and until a fair quantity of seed possessing the special characteristics has been obtained.

In the production of a new variety the aim will be to obtain a perfect plant. There are several points of minor value to each of the various cereals; but the following will be common to all four—wheat, barley, oats and rye,—that the grain be bulky and heavy, that the straw be strong and light, and that the yield per acre of the whole crop shall be above the average yield of other varieties.

The farmer who cannot produce his own seed must depend upon what can be bought from brother farmers or seedsmen proper. To buy it from the latter is probably the better course, owing to the advantages they have, and which the better firms scrupulously employ, for testing, cleaning, selecting, and in all respects obtaining the best seed. Where the seed has received so much attention it will, of course, fetch a high price; hence there are many seedsmen who, to reduce the price, do not attempt to obtain seed of such quality as it is desirable all seed should possess.

There ought to be some standard of quality to ensure the farmer obtaining good seed. The Council of the Royal Agricultural Society recommend the following:—

1. That the bulk be true to the species ordered.

2. That it contain not more than 5 per cent. of seeds other than the species ordered.

3. That the germinating power shall be for cereals, green crops, clovers, and timothy grass not

less than 90 per cent., for fox-tail grass not less than 20 per cent., and for other grasses not less than 70 per cent.

Seed sowing.—When the soil has been brought into a condition fit for the reception of seed, it is termed the seed bed. The seed when placed in it must be able to obtain moisture, warmth, and oxygen gas; hencc a good seed bed is that which provides these wants in the most thorough manner. It is scarcely necessary perhaps to state that the soil should be in as fine a condition as possible. This will ensure that it is moist, and also permeated by the atmosphere, whilst in such a soil the farmer can plant his seeds at whatever depth is most desirable.

The depth at which seed is planted is important, and the smaller the seed the nearer it must be to the surface. If planted too low then the seed may not obtain oxygen, or even assuming that it did, it will exhaust its cotyledon, or reserve food, before it is sufficiently above ground to live on the atmosphere; hence it dies. The larger seed containing a greater quantity of store food can last longer before exhausting its cotyledon, and so may be planted deeper. The smallest seeds, such as grass seeds, are spread on the surface of the land, larger seeds, like mustard, are sown half an inch deep, and the depth will vary with increase of size and peculiarity of structure to 2 inches.

With regard to the time of sowing, it is well to remember that nature sows the seeds in the autumn and upon the surface, though the falling leaves will soon cover the seed with some slight protection. To a certain extent man follows nature, sowing the seed in the autumn and covering it in with soil. There are exceptions, however, as to the time of sowing—barley, for instance, being sown in the spring.

The rotation of crops.—The preceding chapters have gradually unfolded the fundamental scientific facts and principles upon which modern practical agriculture is based, and we now pass to the study of the application of these facts and principles. It must be remembered that the practice of growing crops preceded the least knowledge of the science of agriculture. The precedence of science by practice is indeed a universal rule in the progress of the world. A few facts discovered by one man are transmitted by him to his son, or perhaps lost. Slowly the discovery that certain methods of procedure are advantageous becomes a part of common knowledge. Still there is perfect ignorance of the causes which combine to make these methods advantageous. Thus man is originally governed in his actions by the rule of thumb. Even at the present day this same rule, or want of principle, is to many the guiding force in practical agriculture. Much of the practice now found to be best is that which has long been found to be best, and the task which science has hitherto set itself has been one of explanation rather than of direction. Slowly things are changing, and in the future, probably the near future, science will lead, practice will follow.

A farm is usually divided into two parts: the one part is arable land and used for the production of crops; the remainder is laid down in permanent grass or pasture for the grazing of cattle, and to this is sometimes added a run of 'down' land. The proportion of arable to pasture land depends partly upon economical considerations, though mainly upon the nature of the farmer's business. Practical farming will be comprised under one of four heads:—

I. Arable farming. For the production of crops, where no more stock are kept than are necessary for the labour of the farm.

II. Pastoral husbandry, or cattle farming, where the object is the rearing of animals for the meat market.

III. Dairy farming, where milk and dairy produce are the main considerations; and

IV Mixed husbandry, which combines all the three former objects of growing corn, rearing cattle, and supplying dairy produce.

In describing the practice followed in each of these cases an endeavour will be made to show how that practice is affected by science.

Arable farming must first engage our attention, and, as the keystone of arable farming, it will be necessary to first study *the rotation of crops*, and the reasons how and why the custom of growing crops in a certain definite order has become so universal.

So far as our knowledge of ancient agriculture goes, we find that land was originally cultivated continuously until it was no longer possible to obtain a crop, and then only was the cultivation of the land given up.

Coming to our own island, and to times within the cognisance of history, we find that there was a tendency not to grow any crop in continuity, *i.e.* without break. It was deemed necessary that the land should have a year's rest at intervals. To this resting of the soil has been given the name of *fallow*. In about the thirteenth century the year of rest alternated with the year of growth, and as corn (wheat) was the principal, and the cereals the only crops then cultivated, the farm lands were divided in half; one half bore a corn crop, while the other half lay fallow. As the demand for food grew with increased population, so it became necessary to increase the extent of ground cultivated, and this led to the equivalent result of leaving the land fallow less often, say once in three years, taking two crops in succession. At the same time peas and beans were beginning to be cultivated, so the crops were, if possible, alternated themselves. With the still further development of agriculture, and the necessity of keeping live stock, there arose the necessity of providing them with feed for the winter, and the various kinds of crops becoming by degrees more numerous, the period of rest allowed to the ground became less frequent. Finally, the pressure for crops has attained such a height that the land is not even allowed to remain one year out of three, four, or five entirely at rest, but during this fallow year certain crops are now taken called fallow crops.

The difficulty of deciding what method of cropping was most beneficial to the land soon arose, and it was found that it depended to a great extent upon the nature of the soil. Without attempting to trace its history, the final principle laid down, and which holds good at the present day, is that the better the land the longer may be the period between the fallow years. Gradually then, and according to the nature of the land, certain systems of cropping became fixed and were repeated over and over again in rotation; hence these various systems became known as rotations.

In the earliest system of rotation wheat was the principal crop, and it has remained so up to the present day. The great aim and object of all farming, and therefore of all rotations, was to get the land clean for the wheat crop; everything else was sacrificed to this end. The crops first known were wheat, barley, oats, beans, and peas, and the first attempt to utilise the ground after wheat and before the growth of more wheat was by the growth of beans; hence the first system of rotation would be: fallow—corn—fallow—corn, or fallow—corn—beans—corn; the word corn representing wheat, barley, and oats. No material change took place in the system of rotations until within the last couple of centuries, or, more precisely, not until the turnip and clover crops were introduced. These crops supplied food for cattle; and as the demand for meat increased and English farmers became alive to the value of improving cattle, the use of these crops became more extensive. By degrees clover was found to have certain peculiarities. Firstly, it could not be grown repeatedly with any success, and the soil having become unable to grow clover was said to be sick of it, or clover sick. This occurred on some soils if the crop were taken more than once in eight years, while on some it could be taken every four. Secondly, it was found that wheat when grown after a crop of clover was superior to wheat grown after beans; hence the clover crop took the place of the beans when possible. Thus would be obtained a rotation: fallow—corn—beans or clover—

wheat. Turnips were thus left to come in on the fallow. But turnips would not be out of the ground in time to prepare it for winter sowing, so that wheat could not follow them; and it was a simple and natural result that barley should come after them, this crop being sown in the spring and so allowing ample time to clean the turnips off the land. The following course of rotation was thus obtained: turnips—barley—clover—wheat. Of the many systems of rotation which, in the course of time, came into use, this one soon attained the widest adoption. It originated in Norfolk, is by far the best known system of a four years' course, and is invariably spoken of as the Norfolk, or four-course, system of rotation. This rotation may be said to be the foundation alike of the practical and scientific arable farming of the present day. The question now arises—why? There are several reasons which we can assign to this cause, though probably one or at most two only were known to the original adopters, and are alone considered by most farmers even now.

Firstly, it enables the land to be kept clean. After the growth of the wheat crop, and before the commencement of a new course, there is a long period of rest to the land, at a time when it can be thoroughly cleansed, tilled, and manured. The swedes will be eaten off, or carted off, in ample time to prepare the land for the sowing in spring of the barley, and at the same time the seeds for the clover crop are also sown. Finally, the clover will come to perfection, and be off the land in time for it to be tilled, weeded, and got clean for the autumn sowing of wheat. Thus the system gives plenty of opportunity for thoroughly cleansing the land every four years, and for keeping it clean during the four years.

Secondly, it supplies a sufficiency of manure. At the present day, when the use of artificial manure has become so general, we hardly realise the importance attached to farmyard manure by the farmer of the past. He depended entirely upon farmyard manure, hence any system that did not yield this in sufficient quantity was in his eyes bad. The Norfolk system has not this defect; it supplies sufficient straw for litter, sufficient green food for cattle, and, with good management, sufficient manure for application to the soil before the swedes.

Thirdly, the system has a scientific reason which has probably been at the root of its success, though little recognised. This reason may be stated in general terms thus:—The call upon the soil for mineral matter varies each year. The turnip crop will extract mainly potash and lime, as will also the clover crop. The intervening barley and wheat crops will extract mainly phosphoric acid. Again, the turnips and clover take from the land large quantities of nitrogen, the barley and wheat will extract but small quantities. Thus the stores of plant food in the soil are called into requisition, not in succession but alternately.

Fourthly, plants having short roots, and feeding mostly from the surface, are preceded by plants having long roots, and feeding mainly from the subsoil.

Variations in four-course system.—The most characteristic element of the Norfolk, or four-course, system of rotation is, that it admits of endless variations to suit the requirements of the farmer, his soil, his system of farming, &c. &c. In all these variations the broad principle of the rotation must be maintained, namely, that the two cereal crops be separated by a leguminous crop, and preceded by a fallow, or root crop. Guided by this principle, we may in the first year substitute for turnips, upon land where swedes will not grow, either mangels, carrots, potatoes, or even a green fodder crop, such as rape. In the second year spring wheat may be substituted for barley, though this is not advisable, as spring wheat seldom yields a good crop—that is, when compared with winter wheat, sown in autumn. In the third year, peas or beans may be taken instead of clover; this of course becomes imperative where clover cannot be grown every four years to advantage. Finally, in the fourth year oats may be substituted for wheat.

Other systems of rotation.—Valuable as the four-course system undoubtedly is, yet there are circumstances under which it is not the best possible course. It may be laid down as a maxim, however, that the nearer any rotation approaches to the four-course system the better it is, provided it meets the special circumstances for which it is intended. The circumstances which necessitate a change in the system of rotation are numerous, and it is impossible to separate these circumstances one from the other, and say what course best meets any particular case. They depend I. on the soil; II. on the climate; III. on the farmer's special business, whether it be arable, dairy, or mixed husbandry. Many of these are dependent on one another. Thus the climate affects the crops, the crops affect the live stock and the nature of the farming, and it would be impossible, and useless if possible, to separate the climate from the nature of the farming, and try and give courses of rotation suitable for each climatic condition. The system of cropping must depend principally upon the nature of the live stock kept, and the purpose for which it is kept. Thus, where sheep are kept, roots will be required. Where cattle are kept, a large amount of straw will be required for litter, and of forage crops for food. Then, again, if the cattle are for dairy purposes, they will need much succulent food ; if for fattening, dryer food.

As sheep are mostly to be found where there is light land, and the four-course system being specially adapted to light land, no variation is as a rule needed to meet their requirements. The chief alterations are on heavy land, and due to the requirements of cattle. Thus we find in the North of England, and in Scotland, the four-course system has been extended to a five, or even six, course system, by allowing the clover or seeds to lie down for two or three years, instead of one year only. The course then becomes Roots—barley—seeds—seeds—seeds—wheat. This is an admirable variation for the purpose of dairy farming ; it saves expense of seed and labour ; and though it requires some little care to clean the land after the seeds, yet with good management it does not necessitate leaving the land in a foul condition for the wheat.

For the fattening of stock the chief aim will be to increase the cereals. This may be done in two ways, either by taking two cereal crops of different natures successively, making a five-course rotation—a course only permissible on very rich and well-manured land—

or by taking a second crop of wheat after the first, with the intervention of a crop of beans. Now both of these methods are permissible, though the latter is the most scientific. Thus, where two corn crops are taken together, they will be either oats before the wheat, or barley after the wheat, the rotation being: Roots — barley — seeds — oats — wheat, or Roots — barley—seeds—wheat—barley; whilst of the second system the rotation will be: Roots—barley—seeds—wheat—beans—wheat.

Potatoes are a favourite crop wherewith to increase the rotation; these nearly always precede wheat, and may therefore in the last rotation take the place of the beans in separating the two wheat crops.

In introducing oats into a rotation, it must be remembered that they are somewhat gross feeders, and require the land to be in a fairly good condition, and rich with vegetable matter; hence they are usually taken either after the seeds, or after a root crop.

The following table illustrates the various systems of rotation that have been mentioned in the preceding pages:—

Scientific systems of Rotation.

1st year	2nd year	3rd year	4th year	5th year	6th year
Fallow	Wheat	Fallow	Wheat	Fallow	Wheat
Fallow	Wheat	Beans	Wheat	Fallow	Wheat
Turnips	Barley	Clover	Wheat	—	—
Roots	Barley	Seeds	Seeds	Seeds	Wheat
Roots	Barley	Seeds	Oats	Wheat	—
Roots	Barley	Seeds	Wheat	Barley	—
Roots	Barley	Seeds	Wheat	Beans	Wheat

There are, then, three principal and legitimate ways of extending the course of rotation, as circumstances may require, viz. I. by allowing the clover, and the grass seeds which are in such case generally sown with it, to remain down more than one year; II. to take two different corn crops in succession; III. to take a second corn crop, preceded by a bean or other leguminous crop. By simply varying these methods, an endless number of rotations may and have been formed, which are used in different counties; these, however, do not come within our cognisance, for they have no scientific interest further than has been explained.

So far as rotations are capable of being adopted, such are the principles which govern their selection and their use. It is not, however, every soil, nor yet every climate, which will permit of the growth of all these crops. With regard to the influence of soil, this will vary according to whether the soil is light or heavy. Light soils are peculiarly adapted to the Norfolk system. Turnips grow upon them to perfection, and, when eaten off by sheep, the land not only becomes enriched by the manure, but is consolidated by the treading. The result is a good seed bed for and generally a heavy crop of barley. Hence light land is often spoken of as 'turnip and barley soils.' Heavy soils are the exact reverse; they are not suited for root crops, because the roots cannot be eaten on the land, and even carting them off is a troublesome proceeding, and may be injurious to the soil; hence upon such land turnips are replaced by a forage crop, such as rape, mustard, or cabbage. But heavy lands are well adapted to the growth of wheat, which requires a somewhat firm seed bed, and consequently it is upon heavy lands that the practice of increasing the corn crops, especially wheat, prevails. If, therefore, another wheat crop is required after the fourth year, it is usual to take beans the fifth year, and the extra wheat crop the sixth year. Strong lands are found favourable to the growth of beans, and hence as opposed to light lands are designated 'bean and wheat soils.'

The effects of climate can only be briefly noticed, and in a general way. Of the *cereals*, as regards moisture, barley requires the dryest land, wheat comes next, and oats last. Oats, indeed, flourish in a moist climate. As regards temperature, wheat is most sensitive to cold, barley will grow in colder climates, while oats grow in much colder regions still; thus it is that oats have become so largely grown in Scotland, the climate of which is not nearly so favourable to the growth of wheat.

Of the *leguminous* crops, peas and beans require a dryer atmosphere and a warmer climate than clover or rape.

Of the *roots*, mangels require both heat and dryness; swedes withstand more moisture and less warmth; and potatoes a large amount of moisture, and great variations in climate.

From the preceding analysis and investigation into the principal systematic methods of cultivating the arable land of the farm, and the causes of the benefits arising therefrom, it will be seen that a wise man need be bound by no preconceived or prearranged course of cropping. Given a knowledge of the principles underlying his rotation, he may at any period, and with a little caution, so modify or alter it as to enable him to contend against unforeseen contingencies, without in any way deteriorating his land. Two considerations only he must bear in mind: firstly, that the land must be kept clean; and secondly, that its fertility must not be diminished. Hence, according to the system of rotation he finally adopts, and the subsequent use he makes of the crops, so must be his use of artificial manures.

Of the two great exceptions to the use of rotations, one, the continuous growth of corn, has already been mentioned; the other is market gardening. This species of cultivation takes place around large towns, and the main object is to supply vegetables, &c., as they are in season. It is best accomplished by manuring the land, rather than the crops, using as much manure of a general nature as possible. And in the treatment of the crops, it is advisable to plant them at such a distance apart, that in between every two rows of one crop a crop of some other substance may be cultivated; thus by judicious management one half the land will be growing a crop, while the other half is having a new crop planted, and before the new crop has come to perfection the preceding crop will have been removed, and a fresh one planted in its stead.

CHAPTER XV

THE TREATMENT OF FARM CROPS.

SUCH are the rotations in vogue at the present day. And it is now necessary to more fully describe the treatment each crop receives. Now, the farmer will not have all his arable land in any one crop at the same time, but will generally divide the land into as many equal parts as there are years in his rotation. Thus, while each part of his land follows the same rotation, there will be all the crops of the rotation on the land each year. The following diagram illustrates this where the Norfolk course is pursued and the arable land divided into four parts:—

	Part I.	Part II.	Part III.	Part IV.
1st year	Swedes	Barley	Seeds	Wheat
2nd year	Barley	Seeds	Wheat	Swedes
3rd year	Seeds	Wheat	Swedes	Barley
4th year	Wheat	Swedes	Barley	Seeds

First year's crops.—Fallow crops.—The first year of the rotation is that in which the land is prepared and cleansed for the cropping. Originally no crop was taken, and the land left idle for the year. Pressure of circumstances first introduced crops into this fallow year, and science has now shown that not only are such crops harmless, but advantageous. Land remaining fallow loses by drainage a considerable quantity of plant food, more especially of nitrogen as nitric acid. If there is a crop this loss is diminished, and therefore in modern farming the aim is to keep the land cropped as continuously as is compatible with keeping it clean. The crops introduced into the first year received the names of fallow crops, of which the most important are swedes and mangels; these are also the two principal root crops.

It must be remembered, then, that the chief object in view during the fallow year is to cleanse the land.

As early in the preceding autumn as possible, the land if light is grubbed by the cultivator, or if heavy ploughed, so as to remove the stubble, roots, and weeds left by the wheat crop, it is then allowed to remain until the spring to weather. If the ploughing goes deeper than usual it is liable to bring weed seeds up to the surface which have been unable previously to germinate, and these will give considerable trouble subsequently. Manuring the land will next take place, the farmyard manure being brought out and applied during a frost. In the spring the land may be lightly ploughed, or the cultivator passed through the soil to break it up; subsequently the land is worked with harrows to clean it and produce a fine tilth for the seed bed. Artificial manures, especially phosphatic manures, are now applied. From 20*s*. to 30*s*. worth of a mixed manure, nitrogenous and phosphatic, will be necessary if the land has not had any farmyard manure. If farmyard manure has been employed, then from 2 to 3 cwt. of superphosphate will alone be sufficient.

The seed is sown early in June. About 3 lbs. of fresh seed is required per acre. The seed is sown by drilling machines in straight rows, which are termed drills, and the artificial manures should have been drilled immediately before and below the seed, except any nitrogenous manure, which is to be applied as a top-dressing. The drills should be about 18 inches apart. There is and has been considerable diversity of opinion as to whether it be better to sow turnips on ridges or on the flat. Probably on dry land the flat system is the better; on stiff land, or land liable to excess of moisture, the ridge system. In less than a fortnight the young plants appear, and when they have made a good start, so as to show distinctly above the soil, then the horse-hoe may be passed between the drills to lighten the soil and further clean it. The horse-hoe is an instrument by which knives are made to pass through the ground between each row of plants, several rows being so treated simultaneously The knives pass inwards, downwards, and backwards, so as to allow substances to slide off and not get them clogged. This instrument can have various shaped knives or tines attached to it, and the knives can be set near or far apart, according to the nature of the crop. When the turnip plants are tolerably advanced, or rough leaved, they are *singled.*

Singling turnips, as the word implies, consists in removing at equal distances along every row all the plants save one, usually leaving a single plant at intervals of 9 inches between each removal. As the future crop depends upon this operation, by no means an easy one, being done well, it needs careful supervision. A skilful worker with a hand-hoe can so leave a single plant, but it is better to leave several, and for a boy to follow and remove all but the largest and strongest plant. The singling of turnips leaves them in rows a certain distance apart from each other in two directions—thus, the rows will be of one distance apart, and the plants along the rows also a certain distance apart. This separating of the individual plants is necessary to enable each plant to come to perfection, and it is greater the larger the plant required; but large plants are not really so advantageous as small plants, for, apart from their lesser feeding properties, they do not keep so well. The best practice is to have as great a distance as possible between the rows, but not too great a distance between the individual plants—thus, 9 inches between the plants, and 27 inches between the rows has yielded admirable results, as also 22 inches between the rows and 12 inches between the plants, but it is usual to leave only 18 inches between the rows.

Subsequently the land is hand-hoed and once more subjected to a thorough weeding. Thus it is that the turnip crop enables the land to be thoroughly cleansed. Of the weeds which are to some extent thus got rid of, none is more common or more troublesome than twitch, or couch grass (*Triticum repens*). This weed is of rapid growth and most persistent life. In removing it care must be taken not to break it, for the merest fragment if left in the soil will grow. Couch runs along the ground rooting itself every here and there, and sending up stems wherever it takes root. It is best removed by hand labour, and may be dug out with a fork where the land is tolerably clean. Another weed which frequently causes much trouble is charlock, or wild mustard.

It might seem great waste to sow so much seed and to subsequently destroy the plants. To a certain extent it is, but there are many practical reasons which have led to this custom. In the early stages of the turnip crop it is liable to several diseases, blights, and insect ravages, of which latter none is more fatal than the well-known turnip fly. This is not a fly at all, but a small beetle, or turnip flea beetle, so called from its power of hopping. This insect lives on the young turnip leaves, and the destruction it causes is immense, taking place, however, mainly before the turnips are singled. Nothing except change of weather and wet seems to check the fly, which appears mainly in dry weather with an east wind. Those plants which overcome it in their early stages do not appear to suffer much subsequently; hence the advantage of forcing on the young turnips, and of having more plants than are finally requisite. Where gaps have been made in the field by insects or other causes after singling, these should be filled up with plants immediately

The principal disease to which turnips are liable in their more advanced stage is 'finger and toe,' so called because, instead of a well-formed root, there is obtained a root having the appearance of a number of fingers or toes all clubbed together. This is the result of want of plant food—more generally of lime, sometimes of potash—and it may be prevented from recurring by the application of these substances.

A good yield of swedes will amount to over 20 tons per acre, provided due care be taken in their cultivation. The crop comes to perfection in November, when the roots are pulled, the tops cut off, and the bulbs with the rootlets carried away, or piled in small heaps over the field and covered with earth. The pulling up of the roots should not be delayed too long, nor should it be premature. The ripeness of the crop is generally indicated by the dying off of the leaves, and then the plants should be pulled.

Those roots required for seed purposes must be selected; this is best done by their specifie gravity, those being chosen which sink in a solution of sp. gr. 1·035, whilst the lighter ones are discarded. The solution is made by dissolving common salt in water. The roots taken up each day have the tops eut off, care being taken not to cut too close to the crown of the root. They are then placed in heaps of a cartload or two, and must be covered before night with straw to prevent frost getting at them, for frost destroys the keeping quality of the roots. It is owing to the severe frosts of Canada that farmers do not there grow roots, for they cannot keep them during the winter. When sheep are fed on the roots in the autumn, the roots, as required, are cut up on the field by a machine termed a turnip slicer or pulper; the sliced roots are placed in troughs, the animals being confined to a certain space by hurdles until the produce of that space has been eaten. Sometimes the sheep are allowed to gnaw at the roots as they stand in the ground, the half-eaten roots being pulled up subsequently and sliced.

Land is liable to become turnip sick and eease to grow turnips to perfection; it is then necessary to take some other fallow erop in alternate fallow years.

The fallow crops will be seen to be all forage crops —that is, they supply either in leaf, stem, or root, green food for cattle.

Mangels.—Of the root crops which may take the place of swedes or turnips, the mangel is the most important. It is sown earlier than the swede, about April or May, and consequently comes to perfection earlier. About 4 lbs. to 6 lbs. of seed are required per acre, and the seed must be sown very shallow as it will not germinate if covered with much soil. It is best, therefore, to roll the land heavily before, and very lightly after, sowing the seed. The preparation of the land, the manuring, and the treatment of this crop is very similar to that of the swede. The roots are larger, however, than swedes; hence the drills are further apart, as also the roots themselves, being 2 feet and 1 foot respectively. The mangel is liable to attack by a grub—the mangel grub—whose ravages should be allowed to finish before the plants are singled. In October or early in November the plants are pulled, being seldom eaten on the land as are the turnips. They are peculiarly susceptible to frost, so the sooner stored the better. This is done either in proper rooms, or pits, or by piling the roots up into a heap about 6 feet wide at the bottom, and gradually rising to a point; it is then covered with straw, and finally with a layer several inches thick of soil smoothed so as to allow rain to drain off. The produce per acre is from 25 to 30 tons, being greater than the swede crop by many tons. Mangels are especially valuable for milch cows, and do not give to the butter the peculiar and disagreeable flavour which turnips sometimes give.

The following may be taken as the average composition of swedes and mangels :—

Composition of Roots.

	Swedes	Mangels
Moisture	89·00	90·5
Sugar	5·00	5·0
*Albuminous compounds	·90	1·3
Fibre, &c. &c.	4·50	2·0
Mineral matter	·60	1·2
	100·00	100·0
*Containing nitrogen	·14	·2

Varieties of turnips.—The principal are the Swedish and the common white turnip. The former being the more nutritious is mostly cultivated, though the white turnip is a useful crop at times.

Varieties of mangels.—Mangels are long, or short (globes). There are long reds and long whites; and red globes and yellow globes. The yellow globe is the commonest variety. As mangels improve upon keeping, provided all precautions have been taken, it is usual to first feed off the swedes and keep the mangels for consumption later in the winter. Closely allied to the mangel is the beet, more especially the Silesian sugar beet, which is grown so largely abroad for the production of beet sugar, but cannot be grown profitably for that purpose in England.

Cabbages are sometimes grown as a fallow crop. The seed is first sown in small beds during the autumn, and the plants transplanted to the field either in the later part of the autumn or in the spring. There are several varieties, of which the drumhead cabbage is probably the most used. The land does not require to be so clean as for the swede crop, but of course it must be kept as clean as possible, or the object of the fallow year will be lost sight of. It must therefore be horse-hoed and hand-hoed from time to time. The plants are set about 2 feet apart, and an acre will then require 10,000 plants. If planted 30 inches apart 7,000 will be required. If well manured with farmyard manure and artificials a good crop is obtained. Salt appears to be beneficial to this crop, and 2 cwt. to the acre may be used in conjunction with nitrogenous manures. The cabbage is often planted in ridges; the land is ridged, manured with farmyard manure and artificials between the ridges, and then the ridges are split by the double mould board plough, so covering the manure and forming new ridges in which the plants are sown. The thousand-headed kale is a variety of cabbage largely grown and most useful for winter feeding. The produce of these two crops is enormous, reaching at times, and with good management, to 50 tons an acre. When planted in the autumn cabbages yield a good late spring food, when planted in spring a good winter food. They are somewhat difficult to store, and are not well adapted for converting into silage. The cabbage is a most useful green food and most digestible; it is especially valuable for lambs and sheep before they are given swedes, and few farms should be entirely without some.

The other crops which may be taken in the fallow year are: carrots, parsnips, and kohl rabi, the cultivation of which is very similar in its details to that of the preceding crops.

Second year's crops.—Barley.—The second crop in the rotation is either barley or oats. The swedes will have been cleared off the land or eaten on the land before the winter has set in, and will leave some time to prepare the seed bed for the barley. Firstly, the land must be ploughed as soon as the sheep are off it and the land will carry the horses; generally after there is a frost or some dry weather to harden the land. If the roots have been fed off, then the land will be rich in manure, and no manure will be needed until later; but where the crop has been carted off, farmyard manure should now be placed on the land, and well worked in. The better the condition of the land in the autumn, the less work will it need to produce a good seed bed in the spring; but where sheep have fed off the roots in wet weather, the land will have become greatly consolidated, and need careful attention to produce a good seed bed. It is well to again plough the land in spring. Owing to the sheep having fed off in pens as before described, parts of the land will be in a worse condition than others, and these need careful attention and extra work to make into a good seed bed. In the spring the cultivator is passed through the land, and now it is harrowed as frequently as possible, and especially after a frost. The seed bed having been obtained, the barley is drilled; formerly it was sown broadcast. The earlier it is sown, and the better the land, the less seed will be required; about 8 pecks, that is 2 bushels, may be taken as a fair quantity, but it may require 3 bushels for late sowing on rough land. The land may have a light harrow passed over it after the sowing, and until the plants have advanced in growth, without injury. It is also necessary to hoe the barley.

This is preferably done by hand, but may be done with a horse-hoe if care be taken.

It is sometimes necessary and advisable to top-dress barley with a little artificial manure; this is especially the case when the roots have not been fed off. One or two hundredweights of guano form the best top-dressing, but, owing to the high price of guano, it is becoming the custom to apply a mixture of superphosphate and nitrate of soda; this mixture requires great care in its application. To overcome the difficulty of spreading equally so small a quantity of manure, it is necessary firstly to largely dilute it by mixing with ashes, &c., and to apply it with a broad-cast sowing machine. The land having been hoed and cleaned is sometimes rolled, and then left till harvest. But before this final operation the seeds which are to form the third year's crop are sown, being drilled between the barley drills, or sown broad-cast and harrowed in. Barley is sown in February, March, or April; the earlier the better, but it depends of course upon situation and climate how soon the farmer can get the land prepared. The crop will be ready to reap about the middle of July being one of the first of the cereals reaped, and nearly the last sown.

Barley is a difficult crop to harvest, owing to the ease with which, after once ripe, it germinates not only upon getting wet, but even in damp weather. It is grown, or the best of it is grown, for the brewer, to be converted into malt; and what cannot be so disposed of is used for feeding purposes. For brewing it must satisfy certain requirements, namely, it must contain a maximum quantity of starch, and must be light and uniform in colour. Now, in order to obtain these desiderata, it is necessary for the barley to be dead ripe before it is cut, partly because it feeds very slightly from the straw, so that if cut sooner it would not have a good full ear of starch, and partly because the colour is more uniform in fully ripe grain. When the weather is settled, and the sun shining, it is better to allow the cut barley to lie on the ground, and be subjected to the bleaching action of the sun and air.

The reaping and harvesting of corn crops will be described after the consideration of the other crops.

Varieties of barley.—According to Darwin, there are three species of barley.

The two-rowed spring barley is the one mostly used in England, and the treatment of which has just been described. There are, however, barleys having four rows of grain—these are termed bere—and others having six rows of grain. Winter barley is of this variety. Barley is distinguished by the long awns, which have caused it to be termed bearded. It has a rougher coat than wheat.

Of the varieties there are of course numbers. The chevalier barley probably stands first, at any rate is the kind mostly grown. The cheyne barley is also well known.

Oats require very similar treatment to barley. They are sown in March and April, about 2 to 4 bushels of seed being used per acre. The seed in ripening feeds very largely from the stem, and as the oats, if allowed to get too ripe, are very liable to be shed, especially should there be a storm of wind, oats are cut while unripe. They must not be stacked, however, until the seed has somewhat matured by taking the food from the stem. This is judged by the state of the knots in the straw which should have become dry. Though much of the food contained in the straw is absorbed by the seed, yet it is not all absorbed ; more is left than is contained in wheat or barley straw, and hence the superior value of oat straw as fodder. Oats are used greatly as food for man, and also for horses ; they are a safe food and may be given to sheep with advantage. When oats are given to sheep which are feeding off swedes on the land, they must be first crushed, or some whole seeds are likely to be spilt and spoil the subsequent barley crop.

Varieties of oats.—There are three or four species, but two are best known. The common species, *Avena sativa*, and the tartarian oat, *Avena orientalis.* The common oat grows on all sides of the stem, while the grains of the tartarian oat are disposed on one side. There are black and white varieties of the tartarian species. The ordinary species is white. There is also a red, tawny, or winter oat, which, as its name indicates, is sown in the winter. The white Canadian oat is a well-known variety of the ordinary oat, and the white Poland another. As with all cereals, there are of course numerous other varieties.

Third year's crop.—This crop is usually clover, but sometimes another leguminous crop, such as peas or beans, must be substituted, especially where the land will not grow clover. *Trifolium pratense*, common red clover, or broad clover as it is called, is sown where possible. The clover seeds are generally sown with the barley. By some farmers they are sown immediately after the barley, and harrowed in. Others wait until the barley has just come above the ground, when the seed is sown and rolled in. Rolling the young barley plant will not injure it, provided it is not done when there is a frost; on the contrary, the plant is better for rolling, as also is wheat, and it improves light land. Lastly, some farmers wait until the barley has come up some way, and has been well hoed before they sow the seeds. This is undoubtedly the best plan, both for the barley crop and the clover crop, and should be followed unless exceptional events have caused the sowing of the barley seed to be late.

Clover seed is generally sown broadcast, because it is so small that a drill places too many seeds together; to some extent this may be obviated by first mixing the seed with a diluent. When drilled it is general to drill at right angles to the barley, but the better plan is, as previously mentioned, to pass the horse-hoe along the drills of barley, and immediately after drill the clover up the rows, and subsequently roll. To do this with advantage, the barley should have been drilled in rows 8 inches apart. This method of sowing the clover is especially adapted to those varieties having large seeds. Clover seed requires to be deposited near the surface, not more than ½-inch deep, and great care must be taken to ensure this. The amount of seed varies greatly according to the variety, ranging from 10 to 20 lbs. per acre, according to size. Sometimes it is customary to mix rye-grass with the clover seed, more especially where they are sown broadcast, this is, however, a mistaken practice. Once sown the seeds require no further attention, unless they are to be kept down for some years. It is then customary to give them a dressing of manure after the barley has been removed; this may be either dung where there is plenty on the farm, or instead 2 or 3 cwt. of finely ground bone meal.

Early in May of the third year—the clover year proper—the stock may be turned in on the clover, care being taken not to over-stock the land, for then the plants would be eaten too close to the ground and damaged. After a while the animals are removed, the clover has a time of rest and growth, and may be again fed off later on; in some years of vigorous growth this may be repeated three or even four times. The latter growths are liable to become slightly sour, and require great care, or they may disagree with the sheep and throw them back considerably; this is especially likely to take place with lambs, as they are of course more delicate than sheep.

Clover may if desired be made into hay instead of being fed off; it then forms a most useful winter food, and clover hay is especially serviceable to horses after heavy work. Sometimes the first crop of clover is made into hay, the second crop, or *aftermath*, either being fed off, or else left for seed. When the aftermath is left for seed, the stock must be off the clover, or it must be cut, as early as possible, otherwise the second, or seed crop will not get sufficient sun to thoroughly ripen it.

Varieties of clover.—There are several varieties of clover which differ considerably from one another. Cow-grass (*Trifolium pratense perenne*) is a perennial variety, not grown so much on the four-course system as in longer rotations, where the grass or seeds remain down for more than one year. It does not make, after one year's growth, so good a preparation for wheat as does the common red clover. White or Dutch clover (*Trifolium repens*) is a well-known variety of good feeding quality, but, as it only grows about 8 inches high, it is not made into hay. It requires very shallow sowing, and good rolling. Alsike, or hybrid clover (*Trifolium hybridum*) is also suitable where the seeds are to remain down for several years. Trefoil (*Medicago lupulina*) is of secondary importance. Of these, alsike and cow-grass may be treated in the same way as has been described for red or broad clover. Crimson clover (*Trifolium incarnatum*), unlike the other varieties, may be sown in the autumn of the second year after the barley, instead of with the barley in the spring. Thus, should the seeds have failed which were sown in the spring with the barley, *Trifolium incarnatum* may be planted in the autumn to make good the crop. This variety will only yield one crop, so is not useful where the seeds are required to be down for more than one year.

Where, then, the seed crop is required for one year only, one only of these varieties is used; where required for several years several varieties may be mixed, and it is then usual to mix some grass seeds with the clovers. If rye-grass is preferred, this should be the perennial variety—*Lolium perenne.*

There are two subjects in connection with the clover crop which have been previously referred to, and must now be treated of more fully. The one is that property of land termed clover sickness; and the second is the influence of clover on the wheat crop succeeding it. They may be taken together, for what explains the one explains the other. The roots of clover penetrate to a greater depth in the soil than those of any ordinary crop; hence they derive their nourishment to a large extent from the material of the subsoil. In the chapter on soils it was pointed out that in nearly every case the subsoil is far less rich in plant food than the surface soil. It has also been shown how, of the substances washed through into the drains, nitric acid is the most important; hence the roots of the clover plant, while finding but little mineral matter in the lower soil, find a considerable quantity of nitric acid.

Except upon very rich soil the year's growth will so exhaust the subsoil of both phosphates, potash, &c., as well as of nitrogen, that there will not be sufficient food left for a second crop, or if for a second, not for a third. Now, however liable nitrogen may be to sink in the soil and replenish this loss, it takes some time for any of the mineral constituents to sink and accumulate so as to feed the clover plant; consequently the plant cannot obtain food if taken again soon after the first crop; hence it becomes sickly and dies, the length of time during which it lasts depending entirely on the initial fertility of the subsoil. When the subsoil, therefore, is once exhausted, clover sickness ensues, and it is not amenable to any known system of artificial manuring, for manures are retained in and can only ameliorate the surface soil.

The nitric acid taken up by the clover plant is brought to the upper portion of the roots and stems and there, to a considerable extent, retained. Thus it is that after the growth of clover the top-soil will contain more nitrogen than it did before the crop was grown, even though a considerable quantity of nitrogen has been taken off in the crop. The roots have brought up to the surface the nitrogen of the subsoil, which, added to the nitrogen the soil has obtained from rain and by absorption of ammonia, together amounts to far more than has been taken off in the crop. Hence the land is, so to speak, naturally manured with a nitrogenous manure, and is in a highly favourable state for the growth of a cereal crop, corn crops being, as previously shown, especially benefited by nitrogenous manures. This accounts, then, for the two peculiarities of the clover crop. As the various kinds of clover are found to feed at different depths, it is often possible to grow one kind of clover when another would not grow; and so there is a sort of rotation carried on among the clover crops. Thus the clover crop during the first four years' course may be the red clover, then during the second four years Dutch clover may be used, and during the third four years broad clover again, or, if necessary, peas or beans. Another method of varying the clover is by taking broad clover—alsike—Dutch; the difference between these varieties being sufficient to generally secure a good crop of each. Thus it is possible to separate a red clover crop by eight or twelve years, and so to prevent clover sickness.

Beans.—When these are taken in place of clover, the barley stubble is broken up as soon as possible, and the land manured with dung, this being especially needed by beans. Beans are generally taken on heavy land, and upon land rich in lime. There are two kinds—the winter and spring bean. The winter bean is sown in October or November, being sometimes drilled, though by preference dibbled. In dibbling, a hole is made in the prepared ground with a pointed stick or iron, and the seed dropped in and covered over. The beans are planted in rows from 12 to 18 inches apart, and are sometimes sown on ridges, the manure being got under the ridge as previously explained. The land is kept clean by horse and hand hoeing so long as the plants will permit of the labourer getting along the rows. Beans are a precarious crop, subject to many diseases and blights, and especially to the ravages of black lice. These may be seen in myriads on the plants, turning the stem completely black from their numbers. They destroy the leaves, and the plant consequently dies. Beans are reaped with a hook or the reaping machine, when the seeds in the pod are hard, and are left to dry before being bound in sheaves and stacked. The haulm, or stem, is of great value as fodder; and it makes excellent manure when used as litter.

Peas are best suited to light soils. They require sowing in February or March, and are divided into early and late ripening varieties, of which the early varieties are in many respects the more advantageous, especially as they are less liable to the attacks of insects. Peas are generally drilled in rows about 8 to 12 inches apart, and the land can be well cleaned during their early growth. When the pods are full the peas are cut with the hook or scythe and gathered into heaps to dry; the stem or haulm is used for fodder as well as the seed; the haulm is of exceptional value as compared with the straws of the cereals.

Both beans and peas must be crushed before being given to stock. They are suitable for all descriptions of farm animals.

Closely allied to the clovers are three plants belonging to the leguminosæ, which are used as are the clovers, or as beans.

The vetch, or tare (*Vicia sativa*).—Of this there are two varieties, a spring and a winter. The vetch may be used as green food in spring, in which case it is eaten on the land, or it may be cut first and then eaten off the land. It succeeds on light and strong land. About 3 bushels of seed are sown per acre, either broadcast or drilled in rows from 8 to 9 inches apart. Vetches are specially suited to horses.

Sainfoin (*Onobrychis sativa*) is generally sown to form a permanent source of green food as long as the land will grow it. It is sown with the barley, and treated in all respects in the same way as clover.

Lucerne (*Medicago sativa*) is another forage plant which, like sainfoin, is allowed to remain down several years. This plant prefers a calcareous soil. It is sown in spring and may be cut in the autumn of the same year, whilst in subsequent years it may be cut three or four times.

By degrees both sainfoin and lucerne become stocked with weeds, which would finally smother the crop, but before then the land is ploughed, and where possible it is well to pare and burn land after a long run of these crops.

Fourth year's crops.—Wheat.—Early in the autumn of the third year the land is forked to rid it of couch, then ploughed, and the wheat sown as soon as possible. The seed bed is not required so fine as for other crops, and the clover roots being needed in the soil prevent the thorough cleaning which takes place before and after the sowing of most other crops. The seed is best sown along the furrows, and then harrowed in. These operations should be finished before November, and the earlier the wheat is sown the better is the resulting crop likely to be. Wheat requires a firm seed bed. Like the other cereals wheat is either drilled, or it may be sown broadcast, and about $1\frac{1}{2}$ to 2 bushels per acre of seed are required. It is well not to use more seed than possible, for with thin sowing the resulting plant is better than with thick. Owing to the ravages the wheat seed is liable to, it is usual to pickle it before sowing; that is, to steep it in, or sprinkle it with some solution. This is said to kill both animal and vegetable parasites which may be attached to it. There are many such solutions, such as carbolic acid, sulphate of copper, Down's Farmers' Friend, &c.; they all need care in use, for if too strong, they kill the seed.

The manures used for wheat are generally applied at two periods, the first before the sowing of the seed, and the second in the spring, as a top-dressing. Where the wheat is taken after clover either fed on the land, or even taken off, the soil will, as a rule, be rich enough in organic matter, and the best application to the soil in such case is superphosphate. The application of easily soluble manures not retained by the soil must, of course, be avoided, as much of the manure will have to remain in the land all the winter and part of the spring before it will be required by the plant. Where wheat is taken after a crop somewhat exhausting to the land, such as roots not fed off on the land, but carted away, and the land is not to receive farmyard manure, then a richer dressing of manure than superphosphate must be applied in the winter. Boiled bones finely ground will be of great use, and if a little fish manure or guano be also added it will enhance the value of the crop. Where the seed is drilled it is well to simultaneously drill the manure below it. Sometimes the manure is sown broadcast over the soil before or after ploughing, the land is only lightly ploughed, about 3 or 4 inches deep, and the seed sown on the ploughed land, and harrowed or rolled in.

In the early spring it will be necessary to top-dress the wheat with a nitrogenous manure, which, as previously pointed out, supplies the young plant with the nitrogen then so much wanted. Either guano, nitrate of soda, or sulphate of ammonia may be used for this top-dressing. Upon clay, and especially heavy clay, nitrate of soda is frequently attended with poor results, and sulphate of ammonia may be substituted with advantage. Upon light lands nitrate of soda may be used with good results, and should be applied a little later than sulphate of ammonia. Guano is used upon light and heavy land, and is more especially applicable early in the year upon land which has not received any or but little manure in the winter.

During the growth of the wheat it will be liable to several diseases, of which rust, blight, and mildew are the most important. If wet weather or heavy rains, accompanied by wind, prevail during the latter stages of growth, the wheat will be beaten down and lie flat on the ground; it is then said to be 'lodged.' Wheat with short stiff straw is naturally less liable to suffer in this way than wheat having straw of 5 or 6 feet in length, and as the straw, while taking much nutritive matter out of the soil when so long, also, as a rule, detracts from the yield of corn, the farmer should be careful to select varieties, and so to manage his crop as to keep down rather than accelerate the growth of straw.

Of all the faults which the farmer is most likely to fall into, that of heavily manuring the land with farmyard manure is the easiest. The application of too much farmyard manure tends to make the wheat weak. It becomes liable to rust, and in wet weather to mildew, while it induces a long delicate straw causing the crop to be easily laid. The same results also follow the undue application of nitrogenous manures.

Wheat is ripe when the corn is passing into a thick paste; the crop is not allowed to get dead ripe. Harvest commences in the southern counties in July and does not finish, in the north of Scotland, until the end of September, or later.

Varieties of wheat.—There are an immense variety of wheats, and the number is always increasing.

They may be divided into two classes—White Wheats and Red Wheats.

The White Wheats include:—Chidham or White Swan; Hallett's White; Hertfordshire or Giant White, flourishing on Hertfordshire Chalk; Hardcastle's and Hunter's White; Oakshott's; Sherriff's Bearded; Talavera; Webb's Rough Chaff and Webb's White.

Of the Red Wheats there are:—Browick Red; Eldridge's; Golden Drop; Hallett's Red Lammas; Red

Nursery; Spalding; Square-head (Scholey's); and the April or Bearded Wheat.

Of these wheats very few remarks need be made. In the selection of seed the variety must be considered which is best suitable to the soil and to the climate; thus the White Wheats require a rich stiff soil, while an extreme opposite is found in Red Lammas which does well upon light chalk soils.

Bearded Wheat, also termed April Wheat, it is possible to sow even as late as, and any time during the month of, April; therefore it is largely used to fill up blank spaces in an autumn-sown wheat crop but wheat having been found to yield the best crops when sown in the autumn, the spring variety should never be used unless perforce.

The produce per acre of wheat varies for different varieties, for different soils, and on account of the weather. There should be about 40 bushels of dressed corn, weighing 60 lbs. per bushel. As a rule the weight per bushel is probably more; the yield per acre may vary from 10 to 80 bushels, under exceptionally bad or exceptionally favourable circumstances. Sometimes the crop is given in quarters each of which represents 8 bushels. Then as to straw there should be nearly as many cwt. of straw as there are bushels of dressed corn. Thus the average yield of straw is 1½ ton, or 30 cwt. per acre. Wheat is sold by the quarter, the average price which it has fetched during the ten years, 1872 to 1881, being about 50*s.* per quarter; but the last few years it has sunk to below 45*s.* per quarter. Thus the total value of a crop of wheat is per acre from 8*l.* to 9*l.* plus the straw.

Sale of straw.—The straw is not as a rule sold, and formerly its sale was prohibited. It has been seen in a previous chapter how great is the quantity of nutriment taken out of the soil by the straw. Thus, the straw would contain ·2 per cent. of nitrogen, and four per cent. of ash, and the ash would contain per cent. the following valuable constituents :—

Lime	8·5
Magnesia	5·0
Potash	9·2
Phosphoric acid	3·1
Sulphuric acid	1·0

Then every ton of straw would take from the ground :—

	lbs.
Nitrogen	5·50
Ash, 90 lbs., containing :—	
Lime	7·65
Magnesia	4·50
Potash	8·28
Phosphoric acid	2·79
Sulphuric acid	·90

Now it will be evident that 1 cwt. per acre of a manure having this percentage composition would make up for 1 ton of straw removed. The cost of a manure of this composition would, roughly estimated, be about 8*l.* a ton; so that 8*s.* may be taken as an approximate valuation for the manurial value of 1 ton of wheat straw. Provided care is taken to return the constituents to the soil which the straw has taken out there is no reason why the sale of straw should in the future be prohibited.

Diseases of plants.—All plants have certain critical seasons and trials to pass through, and a number of plants in every field invariably succumb to them. Of these it is only possible to mention a few; those who wish more special knowledge should refer to the inexpensive and admirable works by Miss Ormerod on injurious insects, which, so far as farm insects are concerned, will give our present knowledge. With regard to diseases of a vegetable or fungoid origin, little of a truly scientific nature is known, whilst the methods of overcoming or checking them are most inadequate. We cannot wonder at this. Men have looked upon them as visitations of God, results of weather, and as beyond their control, and due in no way to them. It will be better in the future if farmers first look to their own practice to see if that is at fault, and then to the weather, but never to an influence which is beyond our powers of investigation and amelioration. If it is true anywhere, it is certainly true of nature and nature's laws, that 'all things are for the best.'

Of insects, none cause more devastation, none are more difficult to eradicate, than the wireworm, or grub of the click beetle. Their name at once describes them: long, thin, nearly cylindrical, smooth, bright and tough, veritably like a piece of wire. They infest leys of clover and grass which have been down for years. In the worst cases the land should be pared and burnt; in some cases the ploughed land should receive a good dressing of gas lime; while in others broken rape cake may be applied, which will not only act as a manure, but attracts the worms to it and so saves the crop. Rolling the land heavily has been previously mentioned, and is excellent on light soils. Next to the wireworm, the crane fly, or daddy-longlegs, with its grub known as 'leather jacket,' is probably most hurtful.

Of diseases there are many: *rust* is a red fungus attacking the straw, sucking the juices, and ruining the plant; *mildew* is another kind of fungus, usually white, attacking the crops late in their growth; in 'bunted' wheat the corn turns black from the presence of a fungus. Very similar to this is the 'ear cockle,' but the seed is purple outside, hence it is often called the 'purples'; the microscope reveals in the interior of the seed a number of minute eel-like animalculæ.

Reaping of corn crops.—Formerly corn crops were cut by the sickle, sometimes by the scythe. These, however, are now superseded by the reaping machine, which is somewhat like the hay mower. The chief difference is, that the mower allows the grass to fall of its own accord on the land as cut, but the reaper has attached to it a series of rakes which catch the corn as it is cut, and carry it over a board representing one-fourth of a circle, depositing it finally on the land in a continuous row with the heads all lying one way; from these rows it is easily taken up by the gleaners and made into bundles. Recently reapers have been invented which take the corn as it is cut, and, before depositing it, tie it tightly with string into a bundle, so that a great saving of time and labour is ensured. These bundles are collected together, three or four being placed to lean up against another three or four, and a bundle or two sometimes laid across the top. The heaps so formed are termed *stooks*; and while they permit of the drying and further ripening of the corn in dry weather, they prevent the wheat getting so much damaged by a shower of rain as it would if lying down in bundles. The corn is subsequently carried to the yard and stacked until the time of threshing. Sometimes each stack is thatched, but it is best to have on every farm a large shed under which all ricks may be made; it may be an outlay in the first place, but in the uncertain climate of our island it will in time amply repay the farmer.

The final operation will be the threshing of the crops. Threshing corn was formerly done by flails; at the present day, however, the threshing machine is almost universally used. The machine is driven by steam, and not only is the corn threshed, but the best machines clean the seed, and separate the better seed from the poorer. Thus the seed is divided into 'head,' which is the better, and 'tail,' the inferior corn. The long straw is separated from the short straw, and chaff and weed seeds are also separated. There is a special apparatus for removing the awn from the seed, and the beards where barley is threshed. Before being used, the corn is ground, and thus separated into flour, which is the interior starchy portion of the wheat, and bran, which is the husk; there is generally a third division called middlings, consisting of fine bran and coarse flour mixed.

A good crop of wheat should yield nearly 40 bushels per acre, each bushel weighing over 60 lbs.; a good crop of barley nearly 40 bushels per acre, each bushel weighing over 50 lbs.; oats 50 bushels an acre, each bushel weighing over 40 lbs.; rye will yield about 35 bushels an acre weighing 54 lbs. a bushel.

These will be good crops, and the aim of all scientific farming is to increase not only the number of bushels, but also the weight per bushel. That this is possible there can be little doubt; theoretically the yield might be easily double what it is now, and practically it is sometimes found if not double, yet fifty per cent. above the average.

Having described the main points in the cultivation of our cereals, it only remains to examine their chemical composition. The following analyses by Emil Wolff may be taken as their fair average composition, the variations will be greater or less according to the conditions of growth :—

Composition of Cereals.

	Wheat		Barley		Oats		Rye	
	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain
Water	14·3	14·4	14·3	14·3	14·3	14·3	14·3	14·3
Fat and chlorophyl	1·2	1·5	1·4	2·5	2·0	6·0	1·3	2·0
Albuminous compounds .	3·0	13·0	3·5	10·0	4·0	12·0	3·0	11·0
Extractive matter	36·9	66·4	36·7	63·9	36·2	55·7	33·3	67·4
Crude fibre	40·0	3·0	40·0	7·1	39·5	9·3	44·0	3·5
Mineral matter	4·6	1·7	4·1	2·2	4·0	2·7	4·1	1·8
	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0

Catch, or stolen, crops.—This is the term given to a crop which is taken between two crops of the ordinary rotation. The practice of taking catch crops appears to be rapidly on the increase, and the subject is one which deserves careful attention. For if the farmer can take two crops instead of one in a year, without at the same time deteriorating his land, it is evidently greatly to his advantage. As regards, then, the advisability of a catch crop at any period of the rotation, it must necessarily depend upon whether the cleanliness and general condition of the land will permit it. Catch crops are generally forage crops, and are consequently more often taken where the main object of the farming is the rearing of cattle, and where, therefore, a small amount of land is arable, with a large call upon forage crops. In the four-course rotation, the period which elapses between the gathering of the wheat crop and the sowing of swedes is the time when there is most opportunity for a catch crop. Rape, rye, or tares, may then be grown and fed off green in spring in sufficient time to plant the turnips subsequently. Mustard may be grown in a similar way, and will be ready to feed before winter. This will allow even a second stolen crop, such as early peas, to be sown and fed off before the turnips, though these would be sown late.

Where peas or beans follow barley instead of clover there is also an opportunity of catch cropping. Cole seed may be taken after early peas, and eaten off by sheep. White turnips may also be taken after peas. It has been previously shown that where the clovers fail, *Trifolium incarnatum* may be taken as a catch crop. Thus catch crops may be taken either before wheat or before turnips with advantage, and the quicker a crop comes to perfection the better suited it is for a catch crop. Catch crops are sometimes used for green manuring.

CHAPTER XVI.

PERMANENT PASTURE.

We pass on now to the consideration of that part of the farm which is not arable. This will constitute grass land, more generally known as permanent pasture. The term pasture refers especially to grass which is fed off or grazed, whilst meadow grass is that usually cut for hay. In both cases we have the continuous growth of grass. Such cultivation is the most important part of English agriculture, for over half of the cultivated land is in grass, and the extent increases yearly rather than diminishes, so that the present tendency appears to be to lay arable land down to grass. The laying of land down to grass is an operation of great expense and one requiring considerable care. It is primarily of importance that the land should be thoroughly clean, and this is brought about by any of the methods mentioned in the chapters on the improvement and cultivation of the soil. The land being properly prepared, the next point of importance is the choice of seeds. Unfortunately most farmers leave this to the seedsmen, who, though they have studied the requirements of different soils, can nevertheless seldom supply a mixture so good and so cheap as the farmer might make for himself. The majority of seed mixtures sold for laying land down to permanent pasture are but ill suited to the purpose. Science explains this by teaching us that the various grasses possess various natural qualities which suit them either for prolonged or short life, and that according as we require our pasture to be prolonged or of short duration so should be the grasses sown.

Grasses may be either annual, biennial, or perennial. The first two may be separated from the third division by their possessing this peculiarity: they flower and seed once only, and then die. The perennial grasses flower and produce seed regularly, and yet live.

Now, it is evident that for all permanent pastures, perennial grasses should form the foundation, whilst the annual or biennial grasses are best suited for sowing with clover in those rotations where the seeds are kept down for two or three years only. It must not be supposed that the annual grasses all die the first year. They only die provided they have come to seed; if they do not come to seed then they continue to live; hence such grasses when kept down by stock or cut before seeding may exist for years. They may by coming to seed even increase rather than decrease on pasture; the subsequent natural sowing of the ripe seed giving rise to a far greater number of new plants than would make up for those which die. This has considerable practical bearing, for often sheep and cattle will discriminate between the grasses they eat, choosing some, discarding others: thus a poor grass which is discarded by them may by coming to seed so increase as to materially deteriorate the pasture. To prevent this it is best to mow poor pasture just before the poor grass has shed its seed, or the seed is ripe, but yet after the seed has been formed; by this means the old plants die and young ones are prevented from growing, and so the better quality grasses have more opportunity to thrive.

It is evident from the preceding why in choosing grass seeds for laying down permanent pasture the perennial grasses should be chiefly selected. Grasses may be divided into the coarse and the fine grasses. For permanent pasture the coarse grasses will be well suited, though they should be mixed in due proportions with the finer grasses; then, as the two do not come to perfection at the same time of year, a pasture will be obtained yielding food for stock extending over the longest period of the year possible.

The following list gives the principal grasses, both as regards their popular and scientific names:—

Coarse grasses.

Fescue, meadow (*Festuca pratensis*)
Fescue, tall (*Festuca elatior*)
Cocksfoot (*Dactylis glomerata*)
Timothy (or cat's-tail) (*Phleum pratense*)
Foxtail meadow (*Alopecurus pratensis*)

Fine grasses.

Fescue, hard (*Festuca duriuscula*)
Fescue, sheep's (*Festuca ovina*)
Dog's-tail, crested (*Cynosurus cristatus*)
Rough meadow grass (*Poa trivialis*)
Fiorin (*Agrostis stolonifera*)

Every pasture if it is to be a good pasture must contain not merely grass, but a certain amount of clovers also.

The principal clovers have been previously mentioned; those used for pastures are:—

Red clover (*Trifolium pratense*)
White or Dutch clover (*Trifolium repens*)
Cow-grass (zigzag) clover (*Trifolium medium*)
Alsike clover (*Trifolium hybridum*)

The above are the principal seeds from which will be chosen those required for the pasture. In selecting from these the farmer must consider the nature of his land, climatic conditions, and the stock he purposes to feed. On dry land, foxtail, rough meadow grass and fiorin will not succeed. Indeed every grass has peculiarities of its own which cannot be here entered into. A herb termed 'yarrow' is well deserving of a place in all permanent pastures. The main constituent of all bought mixtures of grass seed is invariably rye-grass; hence the disappointment which so frequently attends their use, because rye grass being an annual is, for the reasons previously given, not suitable. In a few years the pasture suddenly deteriorates.

In laying down land to pasture, therefore, it is essential to buy the seeds separately and to mix them as required. In the mixing of the seed the two following points must be remembered: the percentage number of each variety likely to germinate; and the size of the seeds. It is evident that in 1 lb. of large seeds there are nothing like so many as in 1 lb. of small seeds.

Having chosen the seeds, the next point is to decide how to apply them. On good land, grass seeds may be sown by a broadcast machine as soon as the land has been cleaned and got into a sufficiently fine state for the reception of the seed. On poor land this cannot be done, and it will be necessary to grow some crop simultaneously with the grass seed. In some cases this will be a cereal crop, in others a fodder crop. The latter is where possible the better, especially a quick-growing crop such as rape; but on very poor soils a cereal crop must be taken. As soon as the grasses have obtained a good start they should be fed off by sheep, who are receiving at the same time a food yielding a rich manure, such as 1 lb. of cotton cake per head per diem. When grass land is once established, there is probably no method of improving it more efficacious than this, provided that care is taken never to let the grass be eaten too close to the roots, as its natural growth would then suffer. The application of artificial manures to grass land has been previously spoken of.

The laying down of land to permanent pasture is an expensive and tedious proceeding, and the old Suffolk couplet, if true in the past, is too often true in the present:—

> To break a pasture will make a man,
> To make a pasture will break a man.

In regard to the use of grass land, whether it shall be for grazing, *i.e.* pasturage, or for mowing, we have a few general principles. Sheep require as dry a footing as possible, and probably this as well as the nature of the grass has something to do with the value of mountain grazing lands. It is undoubtedly best, therefore, to select for pastures lands which are naturally dry, and rest on porous subsoils. The reverse holds good for the production of grass for hay. Here lands capable of irrigation, and water meadows, *i.e.* meadows irrigated in a peculiar way with fresh water, many of which are found in the West of England, are more adapted; lands upon cold clay sub-soils, if they are not liable to drought, are also suitable for meadows.

In connection with the subject of permanent pastures, there are some points of scientific interest which have been determined by the extensive experiments of Messrs. Lawes and Gilbert. The principal of these is, that if manures are employed upon grass, the quality of the grass is affected, and the species themselves are liable to vary in number and importance. Thus, upon unmanured land there were found some fifty species of grasses, upon well-manured land only about twenty-five, or one-half, and the grasses that had disappeared were those least valuable. But while on the well-manured grass land the species had halved, the produce had more than doubled.

Of the many enemies to grass land, two only will be mentioned. Moss often proves of great trouble. It appears to depend upon the soil being damp and poor, and is generally found on sandy and peaty soils. Lime and potash seem to affect it most, and by improving the land cause the better growth of the grasses, which can be further augmented by feeding sheep on the land with cotton cake. Weeds when they occur must be kept down by manual labour. Frequently, there will arise coarse sour grass in large patches; a good dressing of salt appears the best way to get rid of these; after such a dressing cattle will sometimes eat the grass which before they would not touch.

Moreover, the salt probably plays an important chemical part in the liberation of ammonia from the stored up vegetable matter of the soil. Sour grass often indicates deficient drainage.

Haymaking.—Grass, which is not eaten on the land, is usually cut and made into hay. In a previous chapter it has been pointed out that grass should be cut just before the seeds are sufficiently ripe to be lost in mowing and the subsequent processes of haymaking. By this means the hay will contain the utmost nourishment possible. Grass was formerly cut by the scythe, but wherever possible it is now cut by the mowing machine. From the moment it is cut to the moment it is stacked it should lose moisture and dry, and it should be stacked as soon as possible after it is dry. Every operation of hay-making has therefore this one end in view, to dry the grass sufficiently for it to be stacked. Unfortunately it is impossible even in the hottest and dryest of summer days to cut and dry the grass and cart it to the rick the same day; hence the grass lies out cut from day to day. Now, apart from the uncertainty of the next day's weather, there will during each night be a certain amount of dew, consequently the operations of haymaking divide themselves into two parts. The one, drying the grass in the daytime, and the second, leaving the cut grass at night in such a condition that it shall absorb the smallest possible amount of moisture from the dew, or from rain in case of a shower. Every night, then, before the labourers leave the field, the hay must be collected into small heaps called 'cocks,' spread uniformly over the field. The day's work will consist in spreading out these heaps, turning the grass and throwing it about or 'tedding' it, so that no two parts shall remain together, but every part come in contact with the atmosphere, and catch the rays of the sun. Formerly the grass was collected by hand-rakes, and even at present often is. The tedding was also done by hand with the aid of a long double-pronged fork. This, however, is almost and should be entirely superseded by the tedding machine, which consists of a number of long rakes, attached to a revolving frame, and placed on a light carriage drawn by one horse. The rakes revolve with the movement of the machine. By means of this machine time and labour are saved, and the work done equally well as by hand. After the tedding for the day has taken place the grass is collected into rows by a large horse-rake, and is then by the hand workers made into cocks. If the grass be cut one day, tedded the next day and made into cocks, and tedded again on the morning of the second day, it may, if there has been fine weather, be carted to the rick in the afternoon; care, therefore, has to be taken not to mow more rapidly than will allow of the subsequent treatment of the grass and the stacking it to take place in due course, and so leave no opportunity for rain to fall upon grass which under a well-managed system would have been carted to the rick. The great evil is rain. It wets the grass, washes out the nutriment from it, causes it to be far more difficult to subsequently dry than the natural grass was, and the resulting hay to be of inferior quality. Great care should also be taken not to cart the hay when damp; if this is done the rick will heat, and so great may this heat become that ricks are often set on fire by it. There will always be a certain amount of heat in the rick, due to the chemical changes going on in the hay, but without these changes hay would not be what it is.

In the building of a rick two precautions are necessary: not to have it too large, and to have it ventilated. It should invariably be made under cover; if not a shed, then under an awning called a rick cloth. The best shape for a rick is a square or oblong; it should not be built on the ground, but upon a stand, or something which, while keeping it from the ground, allows air to circulate beneath it. It is also best to leave a circular or square hole in the centre of a rick by pulling a truss of straw or wooden chimney up as the rick is built. This will cause the rick to be well ventilated, allow the escape of hot air and moisture to be regulated, and lessen the chance of damaging the hay by heating. The hay gradually subsides, and the heat diminishes; after which the rick is thatched. The top of the rick is triangular; the height of the centre may be 1 foot less than half the width of the stack, or what builders term 1 foot under the square; it should not be lower.

The change which takes place in the grass in being made into hay is mainly a loss of moisture; the changes which take place in the hay after it is stacked are the conversion of starch into sugar, a little alcohol, and a trace of acid. Should the heating go too far, then changes take place in the albuminous compounds, and the result is a more or less coloured and charred mass, and a great loss of nutritious matter. The final product of the change is a large quantity of acetic acid; hence heated and charred hay is very acid, and though cattle will eat it, yet it is not so good for them as a much smaller quantity of good hay.

The composition of hay varies according to the grasses from which it has been made, the time of cutting, and the subsequent management, &c. The mean composition of two kinds of hay, ordinary and clover, are shown by the following analyses taken from Professor Emil Wolff:—

Composition of Hay.

	Meadow hay		Red clover hay	
	Mean	Very good	Mean	Very good
Water	14·3	15·0	16·0	16·5
Fat and chlorophyl, &c.	2·5	2·8	2·2	2·9
Albuminous compounds	9·7	11·7	12·3	13·5
Extractive matter	41·0	41·6	38·2	37·1
Crude fibre	26·3	21·9	26·0	24·0
Mineral matter	6·2	7·0	5·3	6·0
	100·0	100·0	100·0	100·0

Owing to the difficulty of making hay while the sun shines, which is so frequently met with in England, and the loss which is caused either by allowing the crop to get over-ripe, or the cut grass to lie in the wet, attempts have been made to discover some method which would enable hay to be made in wet weather. Two only need be mentioned. The one is that of Mr. Gibbs, who carries the hay wet to a machine, where it is dried by hot air, and can then be stacked. The principle involved is excellent, the results satisfactory, and the only drawback is the initial outlay and subsequent expense to the farmer. The second method makes use of the heat produced in a stack made of wet hay to dry it. The hay is carried wet, made into a stack, and through the bottom of the stack there passes a pipe of about 9 inches diameter, connected with a pipe rising vertically in the interior of the stack to its centre. By means of an exhaust fan attached to the outer end of this pipe it is possible to cause a partial vacuum in the interior of the stack, air rushes in from all sides of the stack to fill this vacuum, carrying with it the heated air and moisture of the rick, and so drying and cooling it. This method has been tried during the last few years most extensively, but, it may be truly said, has for the most part failed. In the first place it is based on a wrong principle—the heat necessary to dry the stack being produced by the decomposition of the nutritive matter of the grass. Moreover, the results are never certain, one part of the stack burning while another makes tolerable hay; and, invariably, a large amount of hay becomes spoiled by mould. In time this method may be improved to such an extent as to be used with more advantage than heretofore; what is still required is to know the heat at which the stack should be kept, and the best method of keeping this uniform. The temperature should be taken by means of spear thermometers dug into the rick; if the rick tends to dry on one side only, which is usual, namely, the side the wind blows, then a tarpaulin must be put up this side to intercept the air, and cause the other sides to draw. The round rick will probably answer best, and the ricks must neither be too large nor too close together. Even under the best conditions the resulting hay can never be what hay ought to be.

Ensilage.—On the Continent and in America there is a method of storing green food which has recently been brought prominently before the British farmer. The crop is cut green, and carted direct to a large pit called a 'silo,' where it is trodden down tight until the pit is full; it is then covered over, and subjected to considerable pressure. The pits must be air-tight and water-tight, and are expensive, and the proper weighting of the material is a troublesome operation. The food may decompose until it reaches a stage somewhat similar to over-heated hay, becoming acid from the production of butyric, lactic, and acetic acids. In other cases comparatively little chemical change takes place, and the ensilage does not become acid. At present little is known of the scientific requirements of good silage-making. Probably much depends upon temperature, much to the pressure exerted, and also to the care with which the silo is packed. In England we have no difficulty in growing swedes, and under ordinary circumstances of making hay. In America swedes do not appear to grow well, nor to be capable of storage through the winter, whilst maize grows abundantly, and when cut green can be preserved in silos; ensilage in America is therefore chiefly devoted to preserving maize. Having carefully examined a sample of silage made in America from maize, I estimated the relative value of a crop of swedes as compared with the silage from a crop of maize. Swedes are more nutritious than maize silage, and they take from the ground only two-thirds the mineral matter extracted by the maize, hence, therefore, it is advisable even in America to grow swedes where possible in preference to making maize silage. In England maize cannot be grown with certainty, and there are few crops grown capable of being utilised by ensilage except cabbages and tares; ensilage will probably be carried out therefore only with grass during wet seasons, in which the production of hay becomes doubtful.

The silage made up to the present has with a very few exceptions been acid, and may be described as grass preserved by lactic acid. In the production of this lactic acid considerable changes take place in the constituents of the grass, by which the nutritious compounds, especially the carbo-hydrates, are destroyed. The albuminoid compounds are also changed and probably converted into amides, and these, as previously stated, do not afford food to the animal. Hence silage is less valuable than hay, and the farmer must still endeavour to make hay while the sun shines.

CHAPTER XVII.

THE CHEMISTRY AND PHYSIOLOGY OF ANIMAL LIFE.

In the chapter on the chemistry of plant life it was shown how the plant, taking the inorganic matter from the soil as raw material, converts it into the organic matter of vegetable growths. The animal does not possess this power of utilising inorganic matter, but depends for its sustenance upon vegetable matter; even carnivorous animals subsist on food which primarily came from the vegetable world.

The only other components of animal food are the atmosphere, water, and salt. The atmosphere, so far as we know, is simply of use as a carrier of oxygen. Water, which forms a large proportion of the animal body, is required to augment that present in the vegetable food itself, and salt is, as a rule, required in larger quantity than is generally present in water and food. Whilst the change which takes place in the plant may be said to be a process of de-oxidation, that in the animal is a process of oxidation, consequently the products of the utilised food as well as the excrementitious matters are mostly oxidised products. Of this food there may be mentioned as of special value three compounds: oil; albumen, and allied nitrogenous substances; and starch or similar carbo hydrates, such as sugar. Of these, oil goes in great part to form fat in the animal body; the nitrogenous substances are devoted to the formation of flesh; and starch, sugar, &c. go partly to maintain the heat of the body, and partly to form fat. All three are necessary constituents of the food of an animal. Even though these substances are alone capable of supplying the necessary factors of animal growth, yet they are not alone capable of supporting life. It is not sufficient to supply an animal merely with the requisite quantity of nutriment, the food must have a certain bulk. Bulk of food is necessary no matter how it may be made up. It is chiefly due to the large proportion of water, or else to the cellulose present in most vegetable matters used for food. Though necessary in some quantity, this cellulose becomes injurious when present in excess, especially if it be woody fibre, which, not being digestible, causes irritation in its passage through the intestines, and results in the animal having diarrhœa. This is termed, when applied to animals, 'scouring.' Just the same effect is produced by the opposite extreme, the use of too concentrated a food not having the necessary bulk; hence it happens that concentrated artificial foods, such as the cakes which will be described immediately, often prove injurious when first given to young animals, producing scouring, and sometimes resulting in death.

The composition of the vegetables which make up the mass of animal food has already been mentioned. Salt needs no description; it remains, therefore, to mention water only.

The water which an animal has to drink is of great importance to the health of that animal. Rain, in its passage through the earth, takes into solution a quantity and variety of substances differing according to the nature of the ground through which it passes; hence, when the water again appears above the ground as a spring, or is fetched from a well, it holds in solution certain mineral matters; and it is the presence of these mineral matters in water which gives it that power of destroying soap, termed hardness. The quantity may be small, amounting only to 5 or 6 grains per gallon, or it may amount to several hundred grains per gallon. The great majority of waters, however, will hold only from 20 to 50 grains of mineral matter in solution in a gallon. It is only when the mineral matter held in solution amounts to very much more than this that the water is likely to become injurious to the live stock of the farm. Hard water, therefore, is not so good as soft. The substances most injurious appear to be sulphate of lime and sulphate of magnesia, and the animals most easily affected by hard waters are horses. There now arises a second point of importance. The water before it comes to the animal may flow along a small channel or brook, it may collect in ponds, or it may come from a shallow well. In all cases it runs the risk of coming in contact with decaying matter, of being contaminated with sewage, or of being stagnant. The result is the same chemically—namely, that the water receives, in addition to the mineral matter it originally contained, a certain quantity of organic matter. This organic matter may be harmless; on the other hand, it may be virulently poisonous. Many of the diseases of our live stock are undoubtedly transmitted by germs, and we have had positive proof in the case of men that water has a marvellous power of being the carrier of these disease germs. There can be little doubt but that it is equally powerful in transmitting disease to the animal life of the farm; hence water contaminated with organic matter may at any time prove the carrier of disease from the animal whose excrement contaminated it to the animal who subsequently drinks it. Such water may be comparatively clear and bright to the sight. Water contaminated with organic matter, apart from its effect as a transmitter of disease, may prove injurious to live stock. Cattle are peculiarly susceptible to disease from drinking such water. Good water is therefore necessary for the live stock upon every farm. Next to a deep well, which as a rule gives the purest water, a running brook is the safest. Running water, by the mere fact of its running, is self-purifying, owing to the marvellous power the oxygen of the atmosphere has in oxidising and thus rendering harmless any organic matter which the water may contain.

Of the various substances used as food for cattle the composition of many, especially those of most importance, such as hay, straw, swedes, &c., has already been given. But there are also employed a large number of substances which may be termed artificial foods. These are for the most part feeding cakes. The seeds of some plants, being rich in oil, are placed in bags and subjected in hydraulic presses to immense pressure to extract from them their oil. Owing to this pressure the seeds are completely crushed and caked together when they come out of the press. These cakes are broken up and again subjected to pressure. The oil left in after this is not sufficient to enable the cakes to be again broken up and pressed profitably, so these cakes are sold for feeding purposes and bear the name of the seed from which they have been made. Foremost amongst these cakes comes linseed. The linseed cake left after pressing the flax-seed is a most valuable food for fattening cattle; it is not so good for milk cows, as it sometimes affects the taste of the milk. The composition of linseed cakes—frequently termed 'oilcakes'—is liable to certain fluctuations, due mainly to the degree of pressure to which the cakes are subjected. The greater the pressure, the less will be the oil in the cake, and as it requires far greater power to crush a thick than a thin cake, it is also found that the thinner the cake the less oil will it contain. This is well illustrated if we compare the analyses of English and American linseed cakes. The English cakes are as a rule thicker and subjected to less pressure than the American cakes. The following analyses will show their relative composition:—

Linseed Cakes.

	American		English	
	Very good	Good	Very good	Good
Moisture	7·95	13·05	12·40	12·01
Oil	9·20	8·46	12·43	10·33
Albuminous compounds	33·56	28·12	30·75	24·62
Mucilage, &c.	36·46	35·79	28·20	36·46
Woody fibre .	7·53	8·73	9·87	10·60
Mineral matter	5·30	5·85	6·35	5·98
	100·00	100·00	100·00	100·00
Containing nitrogen	5·37	4·50	4·92	3·94

Apart from its composition a linseed cake should also be pure—that is, free from other seeds. The

American cakes are invariably pure, but English ones are often far otherwise. This may be due either to carelessness or to wilful admixture. Where the impurity is due to carelessness it consists mainly of a variety of weed seeds, which ought to have been screened out of the linseed before pressing. This can easily be done, as such seeds are for the most part much smaller than linseed. Where the impurity is wilful it consists in the admixture with the linseed of substances cheaper and inferior to it; hence in buying linseed cake it is of importance to obtain 'pure' linseed cake, branded as such. It is useless to buy 'A B' or 'Y Z' pure linseed cake. The 'A B pure' is as likely as not to stand for 'anything but pure'; and if complaint is subsequently made the manufacturer retorts that he did not sell it as pure linseed cake, but as his 'A B' pure.

Next to linseed cake comes cotton cake. There are two kinds of cotton seed: one from which the cotton fibres can be extracted, leaving the seed quite free from fibre; and one in which this is impossible, the fibres clinging closely to the seed. This second species, however, has the kernel of the seed quite separate from its outer coating of hard bark, and upon splitting this cortical layer the kernel falls out and can be entirely separated. Both these seeds are employed for obtaining oil, the former kind being crushed whole, whilst only the kernels of the latter are crushed; hence there are two kinds of cotton cake, the one called cotton seed cake, the other decorticated cotton seed cake. They form excellent feeding materials, especially the decorticated cake, which is probably the richest and most economical artificial food known for fattening cows or sheep The cotton seed cakes do not vary greatly in composition, but the decorticated cotton cake is liable to great fluctuations, which are shown in the following table :—

Cotton Seed Cakes.

	Whole seed		Decorticated	
	Very good	Good	Fluctuating between	Good
Moisture	12·10	13·90	6-10	7·90
Oil	7·80	5·33	12-17	14·93
*Albuminous compounds	26·44	20·31	36-46	40·12
Mucilage, &c.	30·53	32·11	20-30	25·03
Woody fibre	18·23	23·30	5-8	5·07
Mineral matter	4·90	5·05	6-8	6·95
	100·00	100·00	—	100·00
*Containing nitrogen	4·23	3·25	5·7—7·3	6·42

Unlike linseed cake, cotton cake is not liable to adulteration. The decorticated cake is, however, liable at times to what proves as bad as adulteration. The decorticated seed when left in heaps before pressing is liable to heat. To check this water is sprinkled over the heap, whilst it is also turned. When this seed is subsequently pressed, the seed where wetted is consolidated into button shaped lumps of great hardness, and if these be given to the animal not broken up they prove incapable of digestion, set up inflammation, and often result in death.

There is one other kind of cake sometimes used for feeding but more often for manure. It is made from rape seed. This seed is usually dirty and liable to contain wild mustard, in which case cakes made from it are injurious to stock.

Besides these three, so to speak, natural cakes, there are many made purposely for feeding, and called compound feeding cakes. Some are good, some bad, and all rather expensive compared with the above cakes.

All cakes must be kept in a dry place; otherwise they are liable to become mildewed, and when mildew gets into the interior of a cake it becomes poisonous. Before used all cake must be thoroughly crushed, and it is well to keep the crushed cake in a dry but draughty place a week or so before using it. By this means it will become much softer and crumble down easily when required for use.

Not only the above cakes but a multitude of substances of every conceivable description are used as feeding materials for cattle, some of which are undoubtedly good, others undoubtedly bad. These substances being generally ground into meal before sale or use, are generally spoken of as feeding meals. The following analyses show the composition of a few of the most valuable :—

Feeding Meals.

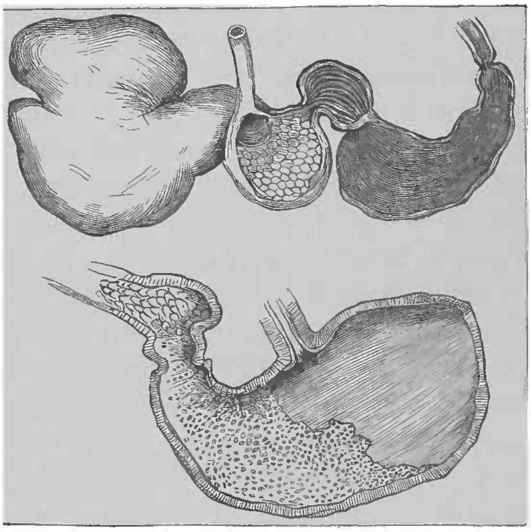
	Palm nut	Rice	Indian corn	Locust bean
Moisture	10·93	14·35	12·70	18·70
Oil	13·70	10·73	4·06	·76
*Albuminous compounds	16·25	11·12	10·25	6·94
Starch, sugar, &c.	34·57	48·62	69·68	63·69
Woody fibre	21·06	6·83	1·76	5·90
Mineral matter	3·49	8·35	1·55	4·01
	100·00	100·00	100·00	100·00
*Containing nitrogen	2·60	1·78	1·64	1·11

Having now some idea of the substances which together constitute the food of the animal, it will be necessary to study the physiological processes which are involved in the conversion of this food into animal matter. This constitutes what is termed the digestion and assimilation of food by the animal. The digestive apparatus of an animal may be said to consist of a long tube termed the alimentary canal, having certain parts differentiated to perform certain functions. The entrance to this tube, viz., the mouth, in all the animals of the farm is provided with teeth for comminuting the food, or rendering it smaller. These teeth vary in number, size, and shape, according to the age of the animal, and are one of the safest guides in discovering the age of an animal. According to the shape of the mouth so will be the method of attacking its food, and this has some practical importance to the farmer. The horse grasps the blades of grass for instance, and then by a jcrk of the head tears away the grass, but cattle use the tongue, firstly, to collcct the grass, and then by a side action of the head cut it off. Sheep are able to get down close to the soil, while cattle, owing to their thick upper lip, cannot get so near the roots of the plants, hence cattle should be placed upon recently laid down pasture, in preference to sheep, who would injure the young grass by eating it off too close to the ground.

During the mastication of the food secretions constituting saliva are poured into the mouth from various glands, and these have a chemical action upon certain constituents of the food, more especially upon starch, which is partially converted by them into sugar. From the mouth the food passes along the alimentary canal into the stomach.

The stomachs of animals may be simple or complex. The stomach of the horse is comparatively simple, that of the pig somewhat more complicated, while that of the cow or sheep is still more complicated. The stomach in its simplest form is merely a pouch-like dilatation of the alimentary canal. As it becomes complicated it becomes divided. Thus in the horse this pouch is divided into two parts, not by a contraction but by change in the internal membrane. The part nearer the heart is termed the cardiac division, the other the pyloric. In the cow and sheep, which are ruminating animals, each of these divisions is again subdivided, both in internal structure and by contractions, so that these animals may be said to have four stomachs. The two divisions of the cardiac portion are termed respectively the *rumen* or paunch, which is an immense sack, and the *reticulum* or honey-comb stomach, so called from the appearance of its internal lining. The two divisions of the pyloric portion are termed, the one *psalterium*, from the fact that its inner coat is raised up into folds which, when the stomach is cut open, 'fall apart like the leaves of a book'—by butchers this part is termed the *manyplies*—and the other *abomasum* or the rennet stomach. These divisions are sometimes spoken of as the first, second, third, and fourth stomachs, being taken in the order just given, the paunch first, and the rennet stomach last. The following cuts will better elucidate these peculiarities. The lower one represents the stomach of a horse, the other the stomach of a sheep.

The part played by the stomach in the process of digestion is twofold: firstly, to act chemically upon the food by means of the gastric juice; and, secondly, to act mechanically upon the food by means of the movements of the stomach. In ruminating animals this action is peculiar, and must now be explained. It cannot be better described than in the words of Professor Huxley:—'A ruminant, when feeding, crops the grass rapidly and greedily, seizing it with its tongue, and



biting off the bundle of blades thus collected by pressing the lower incisors against the callous pad formed by the gum which covers the pre-maxillæ. The bunches of grass are then hastily swallowed accompanied by abundant saliva. After grazing until its appetite is satisfied, the ruminant lies down, usually inclining the body to one side, and remains quiescent for a certain space of time; a sudden movement of the flanks is then observed, very similar to that which might be produced by a hiccough, and careful watching of the long neck will show that something is at the same time quickly forced up the gullet into the cavity of the mouth. This is a bolus of grass which has been sodden in the fluids contained in the stomach, and is returned saturated with them to be masticated. In an ordinary ruminant this operation of mastication is always performed in the same way. The lower jaw makes a first stroke, say in the direction from left to right, while the second stroke and all those which follow it, until the bolus is sufficiently masticated, takes place from right to left, or in the opposite direction to that of the first. While the mastication is going on, fresh quantities of saliva are poured into the mouth, and when the grass is thoroughly ground up, the semi-fluid product is passed back into the pharynx and swallowed once more. These actions are repeated until the greater portion of the grass which has been cropped is pulpified.' 'Neither the paunch nor the reticulum ever becomes completely emptied, even though the animal die of starvation.' This comminuted food now passes into the third stomach, and finally into the abomasum, and here it is that the food comes into contact with the gastric juice.

Arising out of the formation of the stomach are several points of practical importance. The simpler the stomach the more rapid is digestion, and hence the more frequent is the call for food. Consequently, while cattle may be fed only twice a day, horses need to be fed far more frequently; this is why all horses have to be provided with food in nose-bags when out for a day's work. Moreover, when dry foods, such as oats or beans, are given to horses they ne to be macerated beforehand, and softened so as promote their easy digestion ; however advisable, tl is not so necessary with ruminants.

The action of the saliva is mainly upon the starcl matters of the food, which are by it converted in sugar and rendered soluble. No sooner does tl saliva come into contact with the acid secretion the stomach than its action stops. But now tl gastric juice plays its part, and attacks the alb minoids, or nitrogenous compounds of the food, re dering them soluble. From the stomach some of tl more soluble part of the food is partially extract and absorbed into the body. Passing out of tl stomach into the intestines, the food at once com into contact with the bile, or secretion of the live this, being strongly alkaline, neutralises the acid the gastric juice, starts once more the action of tl saliva, or a similar action, by which any starch le undecomposed becomes now decomposed, and al commences a new process of digestion by which tl oil, which has hitherto remained unacted upon, now attacked. A soap, so to speak, is partly forme whilst the remainder of the oil is emulsified—that i divided into such minute particles that it does n separate from water ; in this state it is slowly absorbe by the vessels annexed to the intestines. The foo whilst passing along the immense length of the i testines—these are some eight or ten times as lo as the body—is gradually absorbed until it final reaches the large intestine, from whence the un gested and unassimilated matter is voided. Wh becomes of the assimilated food ?

In every animal three processes are constantly taking place :—Firstly, the maintenance of heat, which results in a consumption of material due to the oxidation of substances necessary to supply this heat; secondly, the repair of waste, by which nature strives to make good the constant loss of tissue which occurs in all living animals; and, thirdly, accumulation of substance, there being a tendency in the animal to store up as much as possible of any excess of food which it may have received and assimilated over and above that required to repair loss of tissue.

The special use which the animal makes of the principal ingredients of its food—viz. oil, albuminous compounds, and carbo-hydrates—has been pointed out already. The heat of the body is maintained by the heat developed in the oxidation of the carbo-hydrates. The nitrogenous compounds go to form muscle or flesh, and hence are termed 'flesh-formers.' But simultaneously with the production of new flesh there is a decomposition of old muscle; and the greater the work performed by an animal the greater the decomposition of muscle in the performance of that work, hence the greater the need of the animal for nitrogenous food. The new food goes to form new muscle, either in place of the old, or, in addition to it, as is the case with growing animals. Hence the nitrogenous substances repair the waste of tissue. The decomposed nitrogenous substance of the muscle becomes oxidised and is voided, mostly in the urine, as urea, uric acid, or hippuric acid. Practically speaking, only one-ninth of the total nitrogen of the food is retained in the animal body; the remainder finds its way into the manure. Hence, the great value of manure made by animals receiving food rich albuminous compounds. Oil is, so far as we can t assimilated directly to form fat. The putting on fat is not generally spoken of as growth, but fattening; and the accumulation of substance in t animal is mainly an accumulation of fat.

In combination with the organic compounds t animal receives from the plant a certain quantity mineral matter; this is of importance, because it required to build up the bones of the skeleton. T most important substance is phosphate of lime, whi constitutes over 90 per cent. of the mineral matt of bones. Thus it is that the feeding of cattle up grass land exhausts the land of phosphate of lin and this also explains why bones have proved such good manure for grass land, because they put ba the very substances the cattle have taken off.

From the preceding facts the following principl may be gathered whereby to regulate the use of foo Firstly, all animals will need an abundance of carb hydrates to maintain heat; secondly, young, i growing, animals require food of a nitrogeno nature: they thus bear a striking resemblance plants, which also, in the early stages of their growt have been seen to require more especially nitrogeno food; thirdly, animals in active exercise and ha work require a nitrogenous food to make up for the great waste of tissue; fourthly, fattening anima require food of an oily character.

But it is evident that whatever tends to dimini waste of tissue diminishes the amount of food n cessary to repair this waste, and therefore will lea a larger excess of food capable of being stored u in the animal as increase, and will consequently help in the fattening of stock. The aim of the farmer in fattening an animal is, therefore, to reduce all waste of tissue. The first call on the food is for the production and maintaining of bodily heat; hence the greater the cold of the animal's surroundings the greater the consumption of food necessary to counteract it. Fattening animals must, then, be kept warm, and warmth will necessarily demand shelter. Secondly, all movement is accompanied by waste of tissue and consumption of food, and if this movement become considerable it is impossible to increase the weight of the animal. Fattening animals are therefore taken out of yards or meadows and placed in stalls or pits. Thirdly, all nervous excitement is as productive of waste as bodily exertion, and consequently bright lights, noises, and frights must be guarded against in fattening stock. Lastly, it must be remembered that oxygen—that is air—is necessary to the health of the animal, and, therefore, thorough ventilation is an absolute necessity for all cattle sheds.

It will be evident that the food of winter should contain far more carbo-hydrates to maintain the heat of the body than should the food of summer.

From the above it is seen that all three constituents, viz., carbo-hydrates, albuminoids, and fat, should be, and indeed must be, present in good food. But the composition of the articles used as food for cattle has shown that the oil, albuminous compounds and starchy matters in them bear no constant relation to one another. Should they do so in the food? With our present knowledge we cannot answer this definitely. We can go so far only as to say that the non-nitrogenous compounds should be greatly in excess of the nitrogenous. According to Wolff it would appear, firstly, that, when young, animals require approximately no less than one-fifth of their food ingredients to be albuminoids and four-fifths carbo-hydrates—that is, having the relation 1 to 4. This is termed the albuminoid ratio of the food. As the animal increases to one year old the relation of the albuminoids to carbo-hydrates becomes 1 to 6, and at two years old 1 to 8. Secondly, that in growing animals the proportion of fat should decrease as the age of the animal increases, while in fattening animals the fat should increase with advancing age.

Many attempts have been made to lay down some definite proportion which the non-nitrogenous matters of animal food should bear to the nitrogenous matters. Mr. Lawes' opinion is that the ratio should be such as we find in the cereal grains, that is 1 to 6. It is, of course, impossible to have any fixed ratio for animals of all ages, and under all conditions. It is, however, well to know the relation between the nitrogenous and non-nitrogenous substances in a food, for it then becomes possible so to diminish or increase this relation, by mixing with other foods, as to obtain the ratio most likely to suit the animal and its requirements.

All attempts to value foods have been unsuccessful and are useless. The attempted valuation may be a relative one or it may be a monetary one. As to the relative valuations, these are of no use, because the value of a food must depend on the purpose for which it is required. The same argument applies equally to the attempted monetary valuation of feeding stuffs—it is impracticable. For instance, the relative values of the ingredients of foods are taken at $\frac{1}{2}d.$ a lb. for starch, $2d.$ a lb. for oil, and $2d.$ a lb. for albuminoids by Henneberg. Upon this basis some well-known foods are ridiculously cheap, others exorbitantly dear. The practical farmer must be guided by the market value of his feeding substances. These values are not far out, being generally the result of practical experience as to their feeding values.

In the commercial aspect of the feeding of animals it is a mistake to lay too much stress upon the value of the manure. The manure, of course, has its value, and the richer the food in albuminoids, the richer also will be the manure. But the increase in live weight should alone pay for the keep of an animal without considering the value of the manure.

CHAPTER XVIII.

THE REARING AND MANAGEMENT OF LIVE STOCK.

In attempting to treat of the live stock of the farm, one must confine one's self to such information as may be legitimately given, and might be sought, in books. Most of the information the farmer will need must of necessity be acquired in the field, for it can only be obtained by practical experience and observation.

Professor Rogers in his 'Political Economy,' writing of the agriculture of the fourteenth or fifteenth century, states: 'In those days cattle were small and stunted by the privations and hard fare of winter. The average weight of a good ox was under 4 cwt. Sheep too were small, poor, and came very slowly to maturity. The average weight of a fleece was not more than 2 lbs.'

How very different are these things at the present day! Yet great though the progress and improvement has been, one must look forward to making it still greater. How is it to be done? To answer this it will be necessary to consider by what means cattle have been made to attain their present condition, and then to gather from that experience the principles which must guide the farmer of the future in the management and improvement of his live stock.

Wherein then does the improvement lie? Just as there are four typical classes of soils, and four typical classes of crops, so there are four typical classes of animals in which the farmer is mainly interested: cattle, sheep, pigs, and horses. In all these animals there are certain qualities in common, whilst each class has its special characteristics. The general qualities now sought—indeed demanded—in these animals are as follows:—

In all four there will be primarily required a power of rapidly attaining to maturity. No matter what the final demand laid upon an animal, it will be best supplied after the animal has reached maturity. Size and weight are the next desiderata. These are more especially applicable to cattle, sheep, and pigs, but sometimes to horses also. To the first three because they will represent a definite quantity of meat; to the horse because they will represent power of draught. But size and weight must not be produced by unhealthy accumulations of fat or other matter; it must be accompanied by strength and proportion, and must represent meat rather than bone. Moreover, the accumulations should not be so rapid nor so excessive as to interfere with the breeding qualities of the animal. In the pig, for instance, meat-producing power will be the main requirement; in cattle and sheep it is associated with others. Thus cattle will be required to give milk, sheep to give wool, though of recent years this too has become quite a minor consideration. The horse, for the majority of agricultural purposes, will be required for its strength, and for its power of stay or endurance. This brief sketch indicates how diverse are the objects the farmer has with regard to his live stock.

Experience soon showed men that nature had laid down certain laws which no endeavours on their part could overcome. Thus that while, by constant care and good feeding, it is possible to improve the condition of most animals, yet that this improvement is unequal. For instance, given a definite regimen and equal care of two sheep, the one will put on more flesh or yield more wool than the other. Similarly with two cows, one will yield more milk or make more flesh than the other. Those animals which failed to supply what was demanded of them were gradually sent to the butcher's, whilst those which satisfied the requisite conditions were kept, and multiplied. Hence there arose an unconscious process of selection by man, whilst simultaneously other laws of nature were operating. Thus under the climatic and local conditions of one district one variety of cattle would flourish, whilst under the conditions present in another place another variety of cattle succeeded; consequently there have arisen with our domesticated animals, just as with the cereals, a number of varieties each possessing peculiarities of its own. These varieties are associated mainly with certain localities, and hence are named after the localities in which, so to speak, they may be termed 'indigenous.' Thus there are Herefordshire cattle, Lincolnshire sheep, Berkshire pigs, and Suffolk horses. What is that law of nature that has caused the stock of one district to continue from generation to generation so similar, yet so dissimilar to the stock of all other districts? It is termed the law of heredity. Such as the father is, such is the son. We all know it to be true when applied to man. We have seen it to be true as applied to plants, and it is equally true of animals. The offspring resembles the parent. But there is an important addition to this general proposition—the offspring does not resemble the parent exactly, it will rather combine the peculiarities of both parents. Having realised this law of nature, the next thing is to utilise it. Men became careful to select for breeding purposes animals possessing special qualities. They endeavoured to compensate for any good quality deficient in the one parent by ensuring its ample presence in the other. Thus they hoped to neutralise in the offspring the deficiency of this parent, while retaining its valuable characteristics. The results have been successful beyond all expectation. Selection in breeding having been carried out from year to year for years past has resulted in the production of live stock of exceptional and constantly improving character, and, therefore, of increasing value. It has been adopted not merely in one district but in many, and so there have arisen many varieties of animals, differing mostly in appearance, but also to some extent in their peculiar suitability for various purposes. Animals thus bred, and not interchanged with animals of a different variety, are termed 'thoroughbred,' or throughbred. A pure breed is finally established.

The following is a list of the chief varieties or breeds which are counted of value :—

Cattle.—Durhams or Shorthorns, Herefords, Devons, Sussex, Longhorned, Norfolk and Suffolk Polled, Welsh, Irish, Jersey and Guernsey, Polled Aberdeen and Angus, Polled Galloway, Highland and Ayrshire.

Sheep.—Leicester, Lincoln, Cotswold, Kentish or

Romney Marsh, Long-woolled, Irish pure native Long-woolled, Southdowns, Shropshire, Hampshire, and West Country Down, Oxfordshire Downs, Dorset, Mountain, Black-faced, Cheviot.

Pigs.—Berkshires, Dorset, Essex, Tamworth, Suffolk, Yorkshires—generally divided into Large-breed and Small-breed Whites.

Horses.—Thoroughbred, Hunters, Carriage, Roadsters, Clydesdale, Shire-bred, Suffolk (peculiarly Agricultural), Agricultural not Suffolk.

Management of Cattle.—In the rearing of all stock, one great principle underlies the whole practice, viz. the animal must never be allowed to lose weight from the time of its birth until fit for the butcher.

The object of cattle rearing is either the production of meat or of milk, and accordingly the rearing and management of these animals depend upon their subsequent use. The constant increase in an animal required for the meat market must necessarily be greater than in one intended for dairy purposes. Where the animal is required simply for the production of meat it is fattened off to be sold sometimes before it is two—generally before three—years old. Where cattle are kept for milking they will also be the rearing portion of the stock. The cow is not sufficiently developed for breeding until she has attained to some maturity, when she is two years old being best. Her food is previously so arranged as to prevent her then being too fat. The bull may be some six months younger than the cow. The time of calving is capable of being arranged to suit the requirements of the farm. Thus the young calves may be born in spring, in autumn, or in winter—at any time when it is liked. But there is a right and a wrong time, and the spring is the right time. To attain this end the bull is placed with the cow in July, the period of gestation of the cow being forty weeks. 'While in calf she can be kept in the most inexpensive manner during the winter; and as spring advances, and the day of parturition draws near, her food should be improved, and she can be allowed a few hours daily in the pastures. The young, rich, juicy grasses will then purify her blood and develop her milking properties. In a few days after calving the mother finds in the pastures the food best calculated to meet her wants at a time when her natural tendency to produce milk is most active. The calf has free liberty in the open air, its vital organs as well as every muscle being brought into healthy action by fresh air and exercise, and the foundation of a robust constitution early laid.' The spring is the most natural time for calving, and the further the time is from the spring, the greater as a rule is the liability of both mother and offspring to suffer injury by the change.

The calf is not allowed the natural milk for more than a fortnight, but is removed from the dam and hand-fed. At first it receives new milk warmed to the natural temperature of the mother's milk, then skim milk is gradually substituted.

The skim milk will often be rapidly displaced by the use of a porridge. This may be made of linseed or linseed cake meal, with wheat meal, or some similar starchy meal added. The meal is first soaked in cold water and subsequently boiled. The addition of some grain rich in starch to the linseed is necessary, because this latter contains too great a proportion of oil and albuminous compounds. A large number of artificial foods are sold for calf rearing under the names of calf meals or milk substitutes. Their composition varies according to the fancy of the manufacturer, and of many samples the few following may be taken as fair representatives :—

Milk Substitutes or Calf Meals.

Moisture	9·10	12·63	19·05	20·35
Oil	4·20	4·86	1·01	·40
*Albuminous compounds .	25·69	16·57	3·62	2·87
Sugar, starch, &c.	48·85	57·63	73·09	74·85
Woody fibre	5·56	4·37	1·93	1·03
Mineral matter	6·60	3·94	1·30	·50
	100·00	100·00	100·00	100·00
*Containing nitrogen .	4·11	2·62	·58	·46

Of these it will be seen the first has an albuminoid ratio of one to two, the second of one to four, the last of one to twenty-six. Evidently they cannot be all good. Even those that are, are sold at such an exorbitant price that a mixture of equal value may casily be made by the farmer himself at about half the cost. And milk being the natural food of the young calf, the nearer the meal approaches to the composition of, or chemical equivalent for milk, the better will it be. The young calf is gradually given hay, cakes, turnips, &c. Great carc is, however, required in feeding the calf until it has earnt to ruminate or 'chew the cud' quitc naturally. This will not be until it is about two months old. The calves are thcn lct out on the pastures, whcre they remain until autumn. In the autumn evenings they are brought in at night to shelter, and as winter approaches artificial food begins to be used.

It is to supply this winter food that the root and most crops have been grown, and it will be augmented by artificial feeding stuffs in proportion to the age and peculiarities of the animals and their subsequent use, being more especially needed if the animal is required for the meat market. This winter food will consist of hay chaff or straw chaff, the latter more suitable for the second winter feeding than the first, turnips sliced or pulped, and equal portions of linseed or cotton cake, and pea, bean, maize, or other starchy meal. As to the quantity, this varies immensely. As a rule straw chaff is given *ad libitum*, sometimes roots also *ad libitum*, and then an animal will eat, if young, from 40 lbs. to 60 lbs. of roots, or, if old, sometimes even more than 1 cwt. per day. The quantity of artificial food is that in which the greatest variation takes place. From 5 lbs. to 10 lbs. of the mixed cake and meal should be used according to the age, nature, and requirements of the animal, this as a rule is ample. As to which of the cakes and meals are best, sufficient data were given in the last chapter to enable a farmer, taking market prices into consideration, to decide for himself. It is almost a universal custom amongst the best farmers to prepare the food of fattening animals either by part boiling or steaming it.

The stock is thus taken through the winter on rich food, which will amply repay its cost by the increased weight and market value of the animals. With those to be sold the whole object is to put on the largest amount of flesh in the smallest possible time, and everything which tends to this end is studied. If the cow is not to be sold, the winter feeding of the first year should be just sufficient to keep her in good growing condition until she is turned out upon the meadows in the following spring, after which she will, in July, be fit to be brought to the bull.

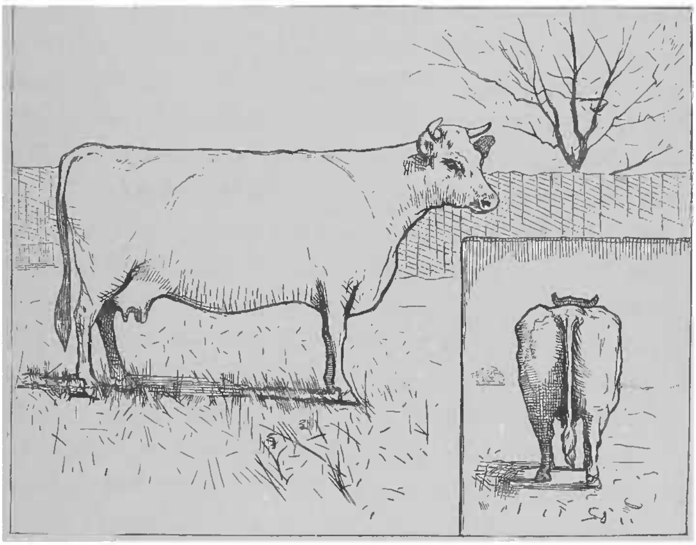
From long years of judicious management the various breeds of cattle have become specially adapted to certain ends—some for the rapid production of meat, some for the quantity of meat, others for the quantity and quality of milk. Few breeds, if any, satisfy all these requirements. The shorthorn, however, combines many of them to an exceptional extent, and it has shown a marvellous power of adapting itself to a variety of climates. Hence the shorthorn is undoubtedly the best all-round breed, and owes to these properties its great value and rapid increase.

The qualities which distinguish a good from a bad animal are termed 'points,' and a description of a shorthorn will, to a certain extent, illustrate what may be termed the good points in cattle generally.

The back must be straight but not too long, but the frame of the animal must be long. The chest wide, deep, and projecting—that is, showing a prominent brisket. The back bones should be level and broad. Hence the back has very much the appearance of a flat rectangular table. The under portion, or barrel, 'round, deep, and well ribbed up towards the loins and hips. The head, feet, and horns are small, the head tapering. The udder is finely quartered. The hair is plentiful, the hide not too thin, and it feels like velvet.'

The following illustrations represent a well-shaped shorthorn, the smaller illustration representing the animal as fatted for the market, viewed from behind.

The various breeds of cattle are distinguished, partly by their general appearance, partly by their horns, those without horns being the 'polled' varieties. The colour and the arrangement of colours is also a guide, which is in no variety so well marked as in the Herefords, with their white faces, manes,



breast, belly, and white feet standing out clearly against the rich red body colour. The colour in other breeds varies greatly: thus in the shorthorn it varies from white to red, a roan or hazel colour being the favourite. It would be useless to attempt to describe minutely these varieties. They will be far better and more surely realised by a few hours' careful observation in the country or at a cattle show than by a far longer time spent over a written description.

In selecting his stock of cattle, a farmer might be at a loss to know which was best to suit his farm. Undoubtedly some cattle thrive better on one soil, or rather on the herbage peculiar to that soil, than do other cattle; hence, where practicable, the breed should be that most nearly indigenous to the locality. Thus in Devonshire Devons will undoubtedly succeed best, while in Norfolk the Norfolk polled will probably be best. Some breeds have but little capacity for thriving under a change of climate, whilst one of the chief characteristics of the shorthorn is this power of adapting itself to different localities and soils, with their numerous consequents. When stock are purchased, no matter of what description, they must be taken from a poorer to a richer feed, and not *vice versâ*.

Management of Sheep.—In the flock of sheep there will be two classes of animals—the ewes and the lambs. Commencing with the latter, they will be of two kinds: the males which, when not required for breeding purposes, will be castrated, fed up, and sold for meat as soon as possible, and the ewes, which, before being sold, will be used for breeding purposes.

In the treatment of sheep, then, three things have to be considered: the treatment of the ewe lambs until they can be used for breeding; their treatment when used for breeding; and the best method of fattening sheep intended for market.

Commencing then with the birth of the animal, we will trace its future development. A fortnight before the ewe is expected to lamb, she is brought to a sheltered and enclosed space which has been constructed specially for the lambing season. Here she gives birth to the young lamb naturally, though the shepherd watches carefully over her during this period and until she is again turned out into the fields. If all goes well the ewe and lamb are, at the end of a fortnight, or even sooner, sent away from the lambing pen to the fields, where the young lambs begin gradually to eat a little of the grass, though subsisting mainly on the mother's milk. The ewes receive, in addition to the pasturage, artificial foods, such as linseed or cotton cake, with meal, and roots. The lambs, while quite young, are castrated, marked, and have their tails cut. They remain with the ewes out on the pasture until the weaning season, when the ewes are taken from them and placed upon less succulent food in order to dry up their milk.

The lambs, especially those required for fattening in the ensuing winter, are now gradually prepared for the eating off of the root crop. This is done firstly by moving them to a rich pasture, the seeds which take the third year in the rotation being especially suitable, or by giving them richer food; and finally, by giving them roots in small quantities, mixed with dry foods, until they are capable of being put on the field to eat the roots off. They are then spoken of as tegs or hoggets. While on the roots, and more especially as they prepare for the butcher, they will receive rich artificial food, of which decorticated cotton cake is undoubtedly the best; beginning at under $\frac{1}{4}$ lb. of such food the amount will increase to $\frac{1}{2}$ lb. per head per day. There will also be added $\frac{1}{4}$ lb. of beans, peas, or other dry starchy food, not so rich as cake, and also hay.

Careful management should enable the hoggets to be sold when ten months old, weighing from 80 to 90 lbs. per head.

Those ewe hoggets which are not being fattened for market should not be richly fed, but merely kept in good growing condition until the following winter, they will then receive a little extra feed before being put to the ram. This takes place as soon as a ewe sheep has attained maturity, namely, when about eighteen months old, and one ram will serve fifty ewes. The ram is usually a shearling—that is, one year old. It is possible, under certain circumstances, for ewes to lamb twice in the year, but once a year is sufficiently often if health and strength are to be maintained in the flock. The period of gestation in the sheep being twenty-one weeks, the ram is placed with the ewes about August, so that the young lambs shall be born in the early spring. The lambing season differs, however, with each county, mainly according to temperature; thus, in the north, it is late, in the south it is early, coming in places even as soon as the beginning of January. Before placing the ram with the ewes, these latter should be selected, in accordance with the principles already mentioned, so that the flock may be ever increasing in strength, quality and condition. Thus, if among the young lambs there appear any weak or malformed, these are best at once fed and sold as meat, and not retained in the flock for breeding purposes. After the ewe has been with the ram the nutritive quality of her food is again lowered, until the approach of the lambing season, when a richer diet will be substituted. Provided a ewe be sound it will serve the ram three years in succession, and after the weaning of the third lambing will be fatted and sold for meat. Exceptions to this rule occur, thus animals whose health fails them will be fed and sold the third or fourth year; whilst animals possessing exceptional qualities are sometimes retained to the sixth year.

During the life of the sheep it will have been necessary from time to time to treat it with a chemical solution, termed a dip, for the purpose of destroying parasites. A sheep-dip should be as colourless as possible, and free from poisonous substances like arsenic.

Before shearing the wool off the sheep, the animal must be well washed; this is done in a pool of water caused by damming up a brook, or better in properly constructed vats; the secretion of the animal present in the skin acts as a kind of soap, but soft soap may also be used with advantage. A little more than a week after the washing the sheep are shorn. It must not be done immediately after, or else the wool is dry and light in weight, but it is done as soon as the natural secretion of the animal, or yolk as it is termed, has once more risen into and pervades the wool, by which time it ought also to be dry.

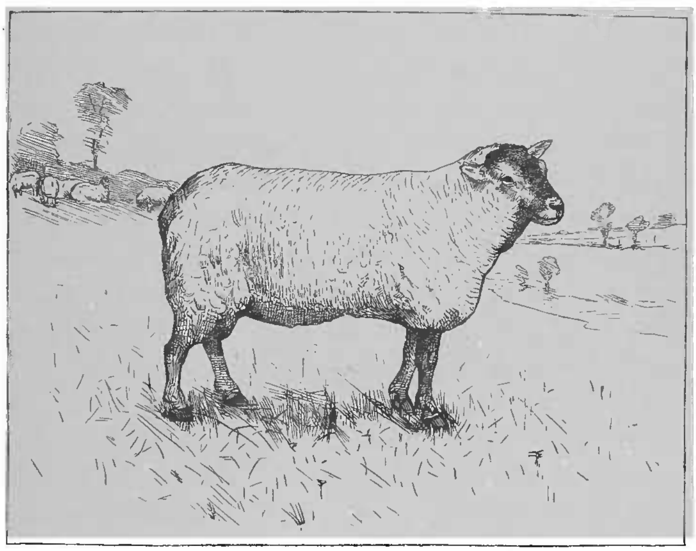
With regard to the production of wool little need be said; this substance is highly nitrogenous, and must necessarily make a considerable demand upon the albuminoid portion of the animal's food, hence starving animals produce but little wool; on the other hand, a rich full diet does not appear to augment the quantity of wool, which depends mainly upon the nature of the animal. The cheapness, however, of wool from Australia is such that it will not pay

English farmers to trouble about the production of wool. What they must seek is the production of meat, and take the wool as it comes. An average fleece will weigh from 6 to 10 lbs., an exceptionally heavy one weighing 20 lbs.

Sheep require a dry soil. Most of the diseases to which they are liable may be traced to a damp soil, which is likely to produce injury as well as disease. The prevalence of the liver rot, or fluke, which has so infested flocks the last few years, has been indirectly due to damp. The feet of sheep will also suffer from foot-rot if not kept dry and clean. The most frequent misfortune to which ewes are liable, and yet by care easily obviated, is abortion. Of the many causes which produce this none is more general than the too rapid change of the ewes from a poor to a rich diet. Sheep are most sensitive to change of diet, especially ewes in lamb, and if the latter are unable to digest and properly assimilate their food it causes inflammation of the bowels, and predisposes to abortion.

Sheep may be divided into three classes: the long-wool, the short-wool, and the mountain sheep. It is the first two classes which have received most attention and been so carefully bred, while the mountain sheep remain more or less natural, though considerable improvements have been made of late in some breeds. The long- and short-wooled sheep, apart from the length of their wool, differ in other essentials. The long-wool sheep yield, of course, heavier fleeces than the short-wooled, they are also heavier in carcass, their mutton not so delicate, and the fat is deposited on their backs, whereas it is deposited internally in the short-wooled. The faces and legs of long-wooled breeds are white, of short-wooled brown or black. The short-wooled are especially prevalent on 'Downs.' Speaking generally, sheep may be said to prefer the hills and cattle the plains.

The qualities which distinguish a good from a bad sheep, or its points, may be illustrated by selecting the modern Leicester sheep as a typical example. In common with the shorthorn cow it will have the characteristic of a straight back from head to tail.



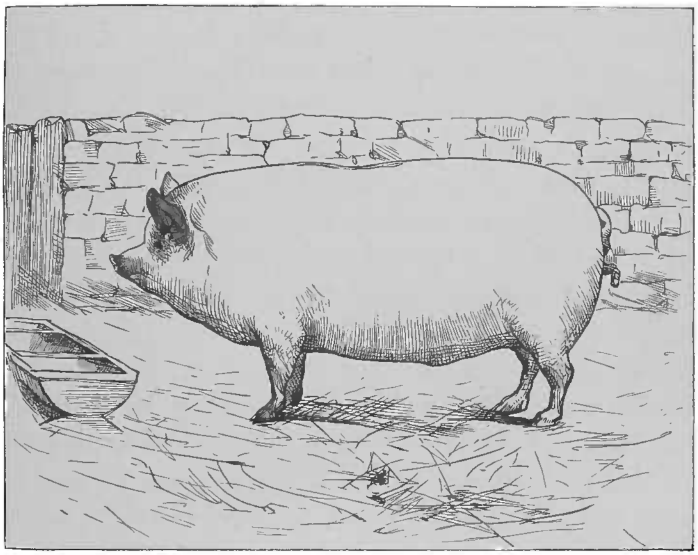
The head is small, the shoulders wide and sloping, and the fore-quarters well developed; the body rectangular, the shoulder and loin well filled up, and the depth of the flank equal to the depth of the fore-part. The bones of the legs are small, and the wool fine and long. The same points may be better seen in the short-wooled varieties, the Hampshires and the Southdowns, the latter famous for their mutton. The above illustration of a Down sheep shows these points.

The sheep will weigh at fifteen months over 80 lbs.

Management of Pigs.—With regard to pigs little need be said; these animals are omnivorous, and therefore their food consists for the main part of leavings, hence it is that they are so frequently left in the manure yard to make manure, turn over the straw, and feed as best they can. Feeding the pigs merely for the meat they produce is sometimes said to leave no profit, except the manure—in such case they are not worth keeping. But in the neighbourhood of towns at least their feeding should be most profitable. The piggery must be warm, dry, well ventilated, and have a stone sloping floor, easily cleaned, and well drained. There should be an iron feeding trough, and a bar of iron should surround the stalls about 9 inches from the ground and from the wall to prevent the sow smothering the young pigs by lying on them. A yard should be easily accessible to the piggery. A pig will be put to the boar in October; and the period of gestation being sixteen weeks, she will have her litter in February.

Before the farrowing of the sow—that is, giving birth to the little ones—only a small quantity of litter should be placed in the breeding house, just enough to prevent the young pigs falling on the stones, not enough to entangle them and so cause them to be laid upon. The sow receives milk and pollard for a few days after farrowing, then returns to her usual fare. The little ones will generally be weaned before the end of two months, and will receive artificial food sooner or later, as they are required for immediate fattening or not. Pigs, young and old, require frequent feeding. The sole object in pig keeping is to fatten the young pigs as rapidly as possible, and as cheaply. The breeds which permit of this are being improved by careful selection, and the small white Yorkshire breed has shown special aptitude to lay on fat, and is less affected by climate than most breeds.

The following illustration represents such an animal.



For fattening a diet is required rich in starch; whilst it is a mistake to load their stomachs with indigestible fibre as is the case with the excessive use of bran.

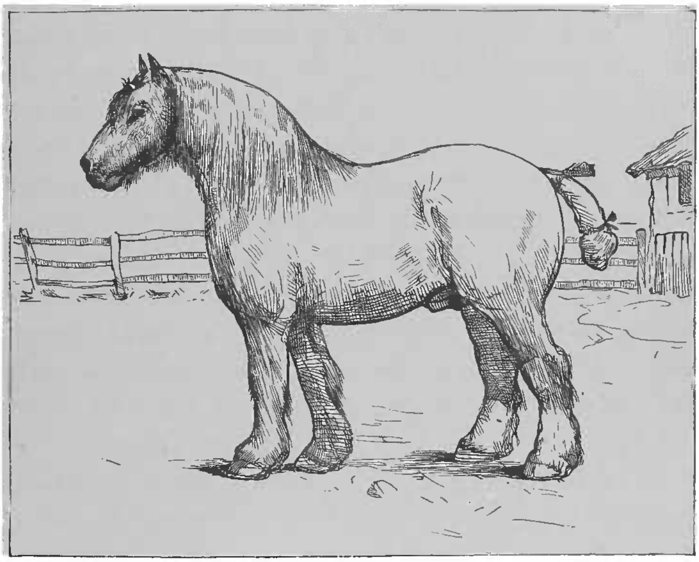
Nearly all the diseases of pigs are due to want of cleanliness and attention.

Management of the Horse.—The horse is one of the animals whose part in farming is entirely that of work, hence there is little breeding and selling of horses. The shire-bred represents the type of animal which, or crosses from which, probably best meet the farmer's demands, and the following illustration represents such an animal.

The question with the farmer is how best to feed the horses required on the farm. The food of the horse is naturally grass, and this will be the food of the young horse, with the addition of some hay in winter. As the horse increases in age, so will it increase in working capacity, and its food will have to become correspondingly richer. Of the richer foods, hay, oats, and beans have been used from time immemorial. The hay is first cut fine in the chaff cutter, and is then termed hay chaff; straw chaff may also be given to the horse with advantage, mixed with its other food. Turnips and clover well cut up, and the former pulped, or even mashed, may be used with advantage in winter and early spring. Subsequently vetches or tares will supply an early and valuable green food before putting the horse out to graze.

A horse must be fed frequently, and its food be prepared for it, grain being crushed, and hay, straw, roots, &c. cut up. The stable must be well ventilated, and contain a supply of fresh water.

Such is briefly the main outline of farming with regard to live stock; the objects which the farmer has in view, how he attains them, and how science has helped him. In the treatment of stock the main object on all farms will be to keep them healthy, and this at the present day is becoming more and more difficult. Everything which tends to the abnormal growth of the animal tends also to weaken it and render it liable to disease, and less able to resist disease when it comes. Hence the greatest precaution should be taken by the farmer to prevent disease, the principle, 'Prevention is better than cure,' being the invariable rule with him. Of the predisposing causes to disease, want of cleanliness may be placed first as most frequent and most unjustifiable; secondly, inefficient shelter; and lastly, contagion. The worst diseases



which live stock are subject to are undoubtedly contagious; therefore, as in man, so in animals, the best possible thing when the least disease occurs in the stock is to thoroughly isolate the affected animals. So important to the general agriculture of the kingdom is this subject of contagious diseases in cattle, that the Government take it up, but not efficiently, for though something is done to prevent the spread of such disease, little is done to prevent the introduction of disease.

CHAPTER XIX.

DAIRY MANAGEMENT AND PRODUCE.

We all know from the time of childhood how the dairy-maid in the 'House that Jack built' milked 'the cow with the crumpled horn.' This 'cow with the crumpled horn' is the old name for the Channel Island breeds. The Channel Island cattle, or Jerseys and Guernseys, the Ayrshire breed and the Shorthorns, are probably the best milkers, and are consequently mostly employed for dairy purposes.

In the feeding of dairy cattle, the object of the farmer is to obtain as much milk as possible; at the same time he has to take care that in producing quantity he does not reduce the quality, for the quality has to be considered, especially where the milk instead of being sold is to be used for the making of butter.

Of the food of milch cows, that which tends most to the production of milk is green food, hence the quantity and richness of milk is greatest when the cows are upon good pasture. But they cannot be on good pasture all the year round, except in a very few places, and in the winter succulent food must still be given, or, more properly speaking, food containing a large proportion of moisture. Turnips are slightly objectionable because the resulting milk, and more especially the resulting butter, become flavoured with a peculiar and disagreeable substance present in the roots. Mangels are not objectionable, as they do not flavour the butter. But the substance finding most favour to supply moisture and to increase the flow of milk, which latter it does in an exceptional manner, is, brewers' grains,—that is, the malt after it has been used by the brewer. The great interest attending the production of silage in this country is mainly due to the fact that farmers hope by its means to find an inexpensive and admirable succulent food for milch cows at a time when they cannot obtain natural grass. There can be no doubt that ensilage will be very largely carried out in the future for this purpose if silage can be shown not to influence the keeping property of the milk, nor yet the taste of the butter. This will be the case more especially in localities where the climate is precarious, or where grass grows so rank as not to be capable of being made into hay, for it is possible to preserve, in a silo or pit, food which, if made into hay, would prove highly indigestible, but which made into silage is to a considerable extent digestible; moreover, it is stated that silage has a similar effect to brewers' grains in stimulating the flow of milk.

In the feeding of milch cows, then, there are two requisites: one, moisture and succulent food; the other, dry, rich, and preferably oily food. In the best dairies it is the rule to give this rich food to the cattle even in the summer, when they are out on the pastures and receiving grass *ad libitum*. The quantity varies from $\frac{1}{2}$ lb. to 3 lbs. per head per day, and decorticated cotton cake takes the preference. Linseed cake is used by some, while others state that like turnips, it has been found to give a peculiar flavour to the milk and butter. Where the milk is sold for town supply, a smaller quantity of cake may be used than where the milk is subsequently made into butter.

During the winter the food of milch cows will be mainly hay chaff, some 15 lbs. per head per day being ample. The moisture and succulent matter will be given in grains, say one bushel per day, and there should be added some 3 to 5 lbs. of a rich food, such as cake or some meal. Some farmers prefer cotton cake, others linseed, some a mixture of the two, while of the meals, Indian corn, pea, barley, oats or rice, either separate or mixed, have each their advocates. Most farmers prefer to soak the meals first before giving them to the cattle. If meal is given without cakes, the quantities should vary from 4 to 8 lbs. Upon sewage farms, where a large quantity of green fodder is procurable during the winter, the quantity of hay is diminished to about one-third, and the grains to about one-half the above quantities, about 75 lbs. of grass being used in their stead; it is then necessary to increase the quantity of rich, dry, artificial foods to double that given in the previous cases, and use from 8 to 10 lbs. per head per day. The preceding brief sketch will show the main principles of the feeding of milch cows. The richer the food the better, and where most farmers who fail in properly feeding err, is in not giving sufficient artificial feeding materials, and in giving too much succulent food or brewers' grains. Grains, while they increase the flow of milk, do not materially diminish its quality, provided there be ample dry food given simultaneously, and the cows are left at the end of a few years in good condition for the meat market.

Milk.—The secretion of milk in an animal arises with the birth of her young, so that it commences in the cow when she is two years old. The first milk secreted by an animal is of a special character adapted to the demands of her young, and to it is given thc name of *colostrum*, no matter from what animal it comes. The colostrum of the cow continues to flow for the first weck or ten days after each calving, and has the following composition:—

Colostrum.

Water	71·6
Oil (fat)	3·4
Albuminous compounds	20·7
Sugar	2·5
Mineral matter	1·8
	100·0

The quantity secreted is at first comparatively small, but it rapidly increases; with its increase in quantity its composition changes, until at the end of a week or ten days the full flow of natural milk takes place, and is continued with very slight variations in composition and quality until within a short time of the cow's drying-up. This is generally at the end of ten months. The normal composition of milk may be taken as closely approaching the following:—

Milk.

Water	87·5
Oil (fat)	3·3
Albuminous compounds (casein)	3·5
Sugar, &c.	5·0
Mineral matter	·7
	100·0

Cow's milk varies, however, in composition with many causes, amongst which the food of the cow, the period of year, the time of milking, the age of the cow, and the lapse of time since calving, are the most important.

Given average beasts, ordinary conditions and fair feeding, a herd should yield milk of the above quality on a fair daily average. The quantity of milk from one cow will vary from one to three gallons per day, or about three hundred to nine hundred gallons of milk from one cow per annum. In the majority of cases, where the cows are selected for dairy purposes, the yield is from five hundred to six hundred gallons per annum, but it may rise to one thousand gallons in the ten months' milking—that is, in the year; this would be an exceptionally good yield.

Milk will be used either for consumption as such, or for conversion into butter or cheese. When used for consumption, the milk must be allowed to cool. For this purpose it is at once brought from the field to the dairy, and is here cooled, either slowly by natural cooling down to the temperature of the dairy, or quickly by artificial means.

Where the cooling is required to be done rapidly, so that the milk may be at once sent away by rail, the cans are dipped in a cool stream, where such is available. But the cooling is best accomplished by a refrigerator, which, however, necessitates a plentiful supply of cold water. The principle of these refrigerators is to pass the milk over a large metal surface, kept cool by cold water running in the reverse direction to the flow of milk, and on the opposite side of the metal; the larger the surface over which the milk flows the more efficient is the cooling power.

Where the milk is required for home use or for conversion into butter it may be cooled naturally in the dairy.

A dairy should always be cool and clean, well ventilated and light. A north aspect, well shaded from the south by trees, and having windows opening north, is preferable. In such a dairy the milk will rapidly lose its heat if set in large shallow pans, and simultaneous with the cooling there rise to the surface the fat globules of the milk. This constitutes cream. Milk is apparently a limpid, white, opaque liquid, which, when mixed with water, to some extent loses its white colour and opacity, and becomes faint blue and more or less transparent. If it be examined minutely under the microscope, it is seen to consist mainly of a thin, colourless liquid, holding in suspension a vast number of round globules. These globules are fat globules, and each of these is known to have a coat surrounding it, which though not visible ordinarily, becomes so if means are taken to extract the enclosed fat. This coat consists of casein, and is the albuminous compound of the milk. The fat globules have a specific gravity lighter than the liquid in which they float, hence given sufficient time they rise to the surface and lie on it, and so form cream. The specific gravity of good milk is about 1·030, and the specific gravity of the cream which separates from it will be about 1·020, or under, and of the skim milk 1·034. Milk is naturally liable to change, and to putrefy, that is, to turn sour; this is owing to the formation of lactic acid, which also curdles the milk. The state of the atmosphere, heat, and dirt are the chief inciters to this change; hence it is necessary that all operations with milk should be carried out as rapidly, at as low a temperature, and as cleanly as possible. Scrupulous cleanness must indeed be observed in all persons and in all utensils with which milk comes into contact. In fact cleanliness is the essential condition of all good and successful dairy management.

Several attempts have been made to render milk less liable to change by adding to it some chemical antiseptic substance, and many powders termed milk preservers are sold for this purpose. They should never be used, under any conditions, except one, and that is in cheese factories. They consist either of borax, boracic acid, or salicylic acid, and are usually sold at an exorbitantly high price. A very large proportion of the total milk consumed is drunk by infants and children, and it is impossible to say what injury would be done to their constitutions if they were fed on milk treated with and containing these chemical compounds. Where milk is to be sent by rail it should be first cooled artificially by means of a refrigerator—that is a sufficient preservative.

Cream is obtained by allowing the milk to stand, and the cooler the milk the more rapidly will the cream rise. The milk set in shallow pans is at a comparatively high temperature; even this, however, must not exceed 55° Fahr. But a system has recently been adopted, known as the Swartz system, in which the milk is set in deeper cans than in the ordinary method, and these cans are placed in others and surrounded by ice. By this means the cream rises in less time than in the shallow pans. The cream is skimmed off the milk twice, once after 12 hours', and again after 24 hours' standing; the first skimming is not mixed with the second. The skimming operation is performed with a flat, perforated metal skimmer, great care being necessary not to take up skim milk with the cream. In Devonshire the milk is scalded, and the cream constitutes the well-known Devonshire clotted cream.

The skim milk left after removing the cream is used for feeding pigs or young calves.

A few years ago a machine was invented which performs mechanically the operation of separating milk into cream and skim milk. It has been followed by a great number, all having the same object and based on the same principle. We know that if a thing be rapidly revolved it has an immense tendency to fly away from the centre of revolution, and if in a vessel there were placed a number of marbles, some of lead and some of wood, and the vessel was rapidly revolved, the heavy leaden marbles would have a greater tendency to fly from the centre of revolution than the lighter wooden ones, and would coat the sides of the vessel, while the wooden ones remained in the interior. This is what takes place in all milk separators. They are vessels revolving several thousand times per minute; the milk is poured into them, the light fat globules are forced to the centre, while the heavier skim milk flies to the circumference, and by very ingenious methods the cream and skim milk thus formed are drawn off separately into suitable receptacles. These machines whilst separating the milk also purify it, and it is astounding what a large quantity of cellular tissue, pus globules, skin, hairs, and dirt, are thus separated from good milk. The skim milk coming from the separator will only contain about ·3 per cent. of fat, so thorough is the mechanical separation. The machines are worked by steam power, and are therefore not suitable for small farms or dairies. They do not require the milk to be first cooled.

Butter making.—As in the preserving of milk, so in butter making, success depends more upon cleanliness and cold than upon anything else. Butter is made from cream. It consists of the butter fat separated from, and washed free of, the casein which surrounds it while in the globular form in the cream. To accomplish this the first operation necessary is to break the casein envelopes and liberate the enclosed fat. This is performed in an apparatus termed a churn, and the operation is called churning. Cream should be churned when at a temperature of 60° Fahr. Of the innumerable variety of churns it would be impossible to say that any single one was the best. The principle of all is more or less the same, namely, to beat or dash the fat globules against a board or boards, and so burst the casein envelopes. These beaters or dash-boards may either be fixed in a movable vessel, or movable in a fixed vessel.

A revolving barrel-churn generally gives the best results; one in which the dash-boards are fixed and are placed at some little distance from the circumference of the churn is preferable. The interior of such a churn can be easily and thoroughly washed and cleaned.

The churn is revolved at a scrupulously regular rate of 60 revolutions per minute, and the moment the cream is converted into butter the sound produced by the churning changes, and the butter is said to have come. The churn must be stopped at once, and the milk which has separated from the butter, and is termed butter-milk, must be drawn off, being passed through a hair sieve to retain any particles of butter, and so prevent loss; these particles must then be returned to the churn. Now the butter-milk carries off the main portion of the casein, but it is absolutely necessary to get the whole of this casein out of the butter, for casein, in common with most nitrogenous substances, is very liable to decompose, and if present in butter this will not keep fresh any length of time. The subsequent operations are therefore directed to wash the remainder of the casein out of the butter; to this end the churn is half filled with water and again turned half a dozen times, the water removed, fresh water put in, and the churning continued; this is repeated until the water comes from the churn as clear as when it was put in.

The butter is now removed from the churn by wooden patters; it must not be touched by the hand. The last traces of water are pressed out of the butter on a wooden slab by means of the patters, or else by means of a corrugated roller, the rolling being repeated over and over again, and the slab kept sloping to let the butter water flow off. The butter will now be made, and where it has to be sent away needs only to be packed. If the butter is required to be kept for a long period it must be salted. This is done by sprinkling salt over it when it is being rolled out on the slab and before packing.

It will be seen that there is no need for the hands to touch milk or butter from the time the one leaves the cow to the time when the latter is packed for sending away. The butter is sent away either in small barrels or in pieces of a certain weight made up separately, and each of which should be covered with clean, fine white muslin. All dairy utensils must be kept clean by repeated and alternate washings with cold and boiling water only; soap must on no account be used. Good butter will contain not more than 10 per cent. of water, 1 per cent. of mineral matter, and under 1 per cent. of casein; the rest will be pure butter-fat. The quantity of butter yielded by a first-class well-fed cow is 1 lb. per day, equal to 2½ gallons of milk.

Cheese making.—Before it is possible to understand the making of cheese it is necessary to know what rennet is. It will be remembered that the fourth stomach of the ruminant is termed the rennet stomach. If the rennet stomach of a young calf be allowed to soak in salt water the liquid at the end of a short period will be converted into what is termed rennet. For the manufacture of rennet on a large scale the stomachs of young calves from Ireland, which are termed 'vells,' are preferred. They are sometimes used almost fresh, sometimes dried and kept for many months before use. The time also for which they are allowed to soak in the salt solution varies from a few days to several weeks, according to fancy, and there are no definite rules which can be laid down as to the manufacture of rennet.

This rennet contains a peculiar ferment, and a few drops of the liquid so prepared have the property of causing the immediate conversion of warm milk into what is known as curds and whey. The curds are white, opaque, and flocculent, and float in the whey, which is a colourless liquid.

Cheese is nothing more than curds treated in a special manner.

For the manufacture of cheese milk is used, either in its natural state, made richer by the addition of cream, or poorer by the abstraction of cream, according to the nature and quality of the cheese to be made. The following description of the manufacture of a Cheddar cheese illustrates the general processes of cheese making. As a rule, one such cheese is made per day, and the milk of some thirty to forty cows will be needed to make it if it be a large cheese like a Cheddar. The evening's milk is not used until the next morning, but is brought into the dairy and set in large shallow pans to cool, so as to prevent any decomposition. The next morning the evening's and morning's milk is placed in a large tub or vat, capable of holding about 150 gallons. This tub is made with a jacket, into which either hot water or steam can be introduced. By this means the whole of the milk is brought to a temperature of 80° to 84° Fahr., and the amount of rennet necessary to convert the whole into curds and whey is then added. The rennet is generally made of such a strength that 1 pint will convert 100 gallons of milk into curds and whey. The curd will rise and set on the surface of the whey in about half an hour. The curd is now cut up with regular rectangular cuts of a curd knife into small pieces the size of peas, and is turned over. After which the contents of the vat are, by means of the hot-water jacket, gradually warmed to a temperature of 100° Fahr. The hot water is drawn off from the jacket, the contents of the vat allowed to stand for half an hour, and the whey removed by a syphon or tap, the latter being preferable, and present in all good cheese vats.

The whey is subsequently allowed to stand, and finally skimmed; for even when great care is taken in the cheese making a certain amount of fat gets converted into butter, and as this does not pass into the curd, it is subsequently skimmed from the whey.

The curd is left for a time to dry, being cut up occasionally with the object of getting it into a fine and cool condition. Subsequently it is packed in thin layers in a tub and pressed, then taken out, broken up, and allowed to further cool. Subsequently it is ground up in a curd mill, about 2 lbs. of salt being added to every 100 lbs. of curd. By these means the curd becomes of a fine texture and uniform character, without which a good cheese would not result. The finely ground curd is finally packed in the tub and placed in a press, where for three days it is subjected to a pressure of one ton. When pressed in the tub the cheese is surrounded by a strong calico band; this is replaced the second day of pressing by another band laced tightly on the cheese, and which will remain on. The cheese is now made, and it remains only for it to ripen. This process takes place in the cheese room, to which the cheese is now taken. The cheese room should be clean, well ventilated, and of a uniform temperature, being kept as nearly as possible at 65° Fahr. The cheese is at first turned over each day; subsequently it is turned less and less frequently. After being in the cheese room for about three months the cheese will have ripened and be fit for the market. The ripening of cheese is a process of fermentation due partly to changes in the nitrogenous compounds, partly to a splitting up of the fat. These changes, however, are not the same in any two varieties of cheese. This is partly owing to the methods of manufacture, but not wholly. Thus it is assumed that each locality has become the home of some specific ferment or germs which become incorporated with the cheese in its manufacture, and produce the changes characteristic of that cheese. Science has yet a large field before it to explain the changes which take place in, and cause the varieties of cheese.

Other cheeses are made in a somewhat similar manner, details varying, however, in every point. Thus, Stilton cheese is made with milk largely admixed with cream, and it is not pressed.

The chief object of the processes in cheese making is to gradually remove the whole of the whey from the curd, and at the same time to ensure the uniform mixing and complete breaking up of the curd into fine portions. Thus the curd, when put in the press, if for a thin cheese, should contain only about 50 per cent. of moisture; and if for a thick cheese, it should contain even less.

All the processes of butter and cheese making may be and are carried out at the present day upon a very large scale in factories. The factory in all respects is more or less similar to a large dairy, and the processes are the same as have been already described. It is in the cheese factory that the use of a small quantity of borax to preserve the milk, which in summer is a matter of great difficulty, is permissible. To hinder the rising of the cream during the night the evening's milk is kept constantly in motion, and this also tends to purify it.

CHAPTER XX.

CLIMATE.

Of the many influences which affect the cultivation of the soil, limit the various crops which it will bear, and determine the nature of the live stock suitable to a given place, none is more powerful than the influence of climate. Hence it is that every farmer should know the nature of the climate of the locality in which he lives, and watch carefully the various changes which it is liable to. It is to be hoped that the time is not far distant when meteorological information will from day to day be widely spread among the agricultural classes, and understood and utilised by them.

The daily and yearly variations in those elements of the climate of the British Isles which are of most importance to agriculture have been recorded and classified; and from the main facts of these certain principles may be adduced.

Temperature.—As the result of observation, it has been shown that the temperature is highest in the south, and decreases towards the north about 1° Fahr. for every 111 miles. It is warmer in the west than in the east, decreasing towards the east about 1° Fahr. for every 66 miles. It is also greatest on the sea level, and decreases 1° Fahr. for every 300 feet above the sea.

These are the main variations in the temperature of the country due to external contour. The cause of the fall in temperature with the rise above the sea level is well understood; probably it is also well known that the warmth of the western and southern shores is mainly due to the warmth of the Gulf Stream by which they are washed, and partly to the warmth of the wind which passes to them from over the Gulf Stream.

Further, there are the fluctuations in the temperature due to the seasons, which, however, are largely modified by the principal factors in regard to temperature just mentioned, viz. external contour, or elevation, and longitude and latitude.

The following table shows the maximum and minimum temperatures of four selected places in England for the four seasons; it also shows the mean daily range, or the degrees of temperature, which the atmosphere passes through daily at each of those places during the four seasons:—

Mean Temperature of England.

	Spring			Summer			Autumn			Winter		
	Maximum	Minimum	Mean daily range	Maximum	Minimum	Daily range	Maximum	Minimum	Daily range	Maximum	Minimum	Daily range
Helston (Cornwall)	58·2	44·0	14·0	68·6	53·6	15·0	59·6	48·3	11·0	48·5	39·8	8·7
Chiswick (Middlesex).	58·0	39·9	18·0	73·1	51·1	22·0	58·8	42·0	17·5	44·1	33·2	11·0
Nottingham .	56·7	41·0	15·7	75·2	56·4	19·0	57·3	45·3	12·0	42·6	34·9	8·0
Thwaite (Suffolk)	54 0	40·4	14·0	70·6	52·9	18·0	56·8	44·5	12·0	42·0	33·7	8·0

A careful consideration of this table shows that, while the highest temperatures on the western and southern coasts are greater than on the eastern and in the north, there is a far more marked difference between the lowest temperatures of these localities. Consequently plants and animals are in the west and south far less liable to extremes of heat and cold than they are in the east and north. Though the difference is but small when stated in degrees of temperature, yet in its practical results the effect of this difference is great. Even though it does not prevent the plants and animals cultivated or bred in the west from being cultivated or bred in the east, still it does materially affect the conditions under which these operations take place. Thus in the west plants must be sown earlier, and they come to perfection earlier than in the east. Animals can be born earlier, and kept out longer. Indeed, not only in such broad generalisations, but more especially in minor points are these variations in temperature accompanied by variations in practice.

Light.—Both temperature and light depend upon the sun's rays, hence light is closely connected with temperature. Light is essential to plant growth, and everything which robs the light from a field, robs the field of its productive qualities. The recent electric experiments of Siemens have very forcibly demonstrated the effect of light on vegetation. It appears from them certain that, given the other factors of growth, a field of corn would continue to grow during the night if it were not for the absence of light, and that the effect of light is undoubtedly equal to an immense stimulant exerted on the growth of the plant. How this acts has been shown in the chapter on the Physiology of Plant Life.

Wind.—The direction of the wind greatly affects climate; although we generally consider the wind never blows twice in the same direction, yet observation has shown that there is a preponderance of certain winds passing over our country. Thus, at Greenwich, the wind has blown, taking the average of many years, in the following directions upon the number of days per annum mentioned in the following table:—

Mean Annual Direction of Wind.

From the South-west		104	days
North-east.		48	,,
North		41	,,
West		38	,,
South		34	,,
North-west		24	,,
East		22	,,
South-east.		20	,,
	Calm	34	,,
		365	,,

By seeing how these winds are distributed over the various months, some very interesting results are obtained, which are of value, because not only the temperature, but the rainfall, depend largely upon the direction of the wind, and many farmers would say blights and insect attacks are also influenced by the direction of the wind. Without entering too much into detail, the following table will illustrate the number of days per month the wind blows from a more or less easterly direction and from a more or less westerly direction. The wind blows from the other points of the compass, N. and S. about equally three or four days in the month, the north wind being a little more prevalent; the remaining days are calm:—

	E., N.E., and S.E.	W., N.W., and S.W.
January	6·15	14·75
February	6·95	12·80
March	8·65	13·70
April	11·55	11·10
May	11·15	10·85
June	7·35	15·65
July	5·40	16·95
August	5·45	16·25
September	8·75	11·30
October	5·45	15·40
November	7·60	11·90
December	5·60	15·75

This table illustrates most strikingly the reason of the cold in April and May, and of the warmth of July and August. In these two months the wind blew from the S.W on 10·55 and 10·45 days respectively. Other points will be mentioned hereafter.

Rainfall.—The quantity of rain which falls upon any place in England varies:—1st, for each year; 2nd, for each month; 3rd, according to its geographical position; and 4th, according to its local position.

Yearly variation.—The largest yearly fall of rain which has been recorded at Greenwich of late years has been 35·31 inches, the smallest quantity 16·74 inches; whilst the average rainfall for the past half-century has been about 25 inches.

Monthly variation.—The average monthly rainfall of this period shows that February and March give the least rain, the other months being fairly equal, with the exception of July and October, which are invariably wet months.

Mean Monthly Rainfall.

	Average 50 years	Eastern side			Western side		
		York	Norwich	Cobham	Keswick	Manchester	Truro
Jan.	2·0	1·72	1·97	2·24	4·87	2·31	4·66
Feb.	1·5	1·02	1·45	2·38	2·63	2·56	3·79
Mar.	1·6	1·19	1·16	1·72	4·60	2·09	3·44
April	1·7	1·50	1·79	1·21	4·24	2·01	2·54
May	2·0	1·41	1·91	3·19	3·02	2·90	2·41
June	1·9	2·35	1·77	1·44	4·12	2·50	2·79
July	2·6	2·65	3·10	2·27	4·94	3·69	2·64
Aug.	2·4	2·93	2·76	2·93	5·85	3·66	3·04
Sept.	2·4	2·08	2·48	3·57	4·41	3·28	3·68
Oct.	2·8	2·09	2·94	2·88	9·00	3·92	4·08
Nov.	2·4	1·75	3·02	4·41	8·35	3·36	6·11
Dec.	2·1	1·31	1·74	1·96	6·66	3·83	4·90
	25·4	22·02	26·09	25·25	62·72	36·14	44·08

The reason why July is a wet month is evident, the previous remarks having shown that the south-west wind, which is invariably a wet wind, is more prevalent in that month than in any other month of the year. It is evident then that, in the face of these facts, the farmer who leaves till July operations requiring dry weather is blind to facts, and that those who want to make hay while the sun shines must do so before July.

Geographical variations.—The previous table gives the mean monthly rainfall over three typical eastern towns, and three typical western towns. The difference is striking, and shows how much wetter the western counties are than the eastern. Upon examining the rainfall in the south-west and middle of England, the average rainfall is found to gradually increase on passing from east to west. In round numbers we may take the average rainfall of—

The North-west to be	38 inches
The South-west	34 ,,
The Centre	28 ,,
The East	24 ,,

These variations affect in many ways the methods of cultivation practised in the different districts.

Local influences.—There are some very curious statistics to show that certain localities are peculiarly wet when compared with the surrounding neighbourhood, others peculiarly dry. Thus there is a small isolated district, comprising part of Hertfordshire, Buckinghamshire, and a small portion of Bedfordshire, where the average rainfall is between 25 and 30 inches, while the average of these counties outside that area is under 25 inches.

Thus the average monthly and annual rainfall at Rothamstead, which lies within this high rainfall district, is 28·09 inches, and of Hitchin, a town only ten miles away from Rothamstead but outside this high rainfall district, only 24·66 inches.

Again, in the West of England, the distribution of rain is most unequal, which mainly results from the difference of elevation of the land, and of the form and slope which the surface presents to the rain-depositing wind. To take one example: The annual fall in the wide, open, and flat estuary of the Taw is 25 inches; as the valley contracts at Barnstaple the rainfall has risen to 40 inches, whilst on the skirts of the high land of Exmoor it reaches 60 inches. This illustrates a well-known fact that the rainfall on the hills increases with their height. There is no better illustration of that than one in Cumberland. At Whitehaven, on the coast, the annual rainfall was

40 inches, whilst on the Stye, 1,077 feet high, the rainfall had risen to 224 inches.

Salisbury Plain may be taken as an instance of a place where the rainfall is exceptionally low, of which there are many such. Though lying 600 feet high it receives only 23 inches of rain per annum, less even than Greenwich, which is only some 100 feet high. Again at a station on Snowdon, 300 feet high, the rainfall was over 100 inches; another station 1,000 feet high gave only 58 inches of rain.

It is very essential therefore that a farmer should know the rainfall of his farm, whilst it is evident that the greater the rainfall the greater the necessity of draining the land. The small difference in the rainfall between a dry and a wet season is almost incredible when compared with the enormous effect which it produces. This effect is often due not so much to the quantity of rain as to the time at which it falls. The ill done by quantity alone will depend mainly on the physical properties of the soil, and will generally be less upon drained than upon undrained land.

These facts have been given to draw attention to the influence of climate generally rather than to enable any further practical deductions to be made—the most important having already been stated in previous chapters.

Every farm, however, may be said to have a climate of its own; and the object of the owner should be to discover this climate, and if necessary, to modify it. Nothing is more striking in its effects than the shelter of a farm, and this may be controlled. An exposed situation is necessarily at times much colder than a sheltered one. So important is shelter that two farms may sometimes be seen at a considerable elevation, upon one of which good crops cannot be grown, whilst upon the other excellent crops are grown; the main and only apparent difference being in the shelter which the latter has but not the former. Frequently shelter is due to position; this it is which augments the fertility of valleys well sheltered by surrounding hills. Shelter may to some extent be procured artificially by the planting of trees, underwood, or hedges. In choosing a farm its aspect should also be considered. Finally, the better a farm is worked the better will be its climate, and the better the climate the better the crops. Just as the climate of England prevents the cultivation of the vine, so largely cultivated in France, so the climate of one farm or part of England may be totally unsuited for the production of a crop profitably raised within a comparatively short distance.

The geological structure of England influences the surface-shape of the island; this surface-shape, or contour, affects the climate, and the climate affects the agriculture. It would be useless for agriculturists to attempt to defy the phenomena of nature resulting from these peculiarities; what they have to do is to study them so as to utilise them. This has already been done to some extent, if not knowingly, at least effectively. Thus the warm, wet, western counties, with the luxuriant natural produce they entail, have gradually become mainly grazing land, devoted to the maintenance of cattle, and the production of milk, butter, and cheese. The colder and dryer eastern counties have simultaneously developed their more natural resources, and been converted mainly into arable land for the production of corn.

Agriculture, then, depends for its success upon many circumstances, some within the control of the farmer, some beyond his control. Success is never certain, but it is possible, and highly probable for him who exercises observation, patience, and perseverance in his practice, and combines with that practice a knowledge of the science of agriculture.

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